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UNIVERSITY OF ALBERTA

INTEGRATED CONSTRUCTION BIDDING SYSTEM

BY

©

SHELDON L. SCHROEDER

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfillment of the requirements for the degree **MASTER OF SCIENCE IN CIVIL ENGINEERING**.

DEPARTMENT OF CIVIL ENGINEERING

EDMONTON, ALBERTA

SPRING 1993

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UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

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DATE: April 15, 93

Abstract

This research involves the development of a bidding system for the purpose of determining a bid markup on a construction tender in the competitive bid environment. Previously developed bidding models utilize a single theory of analysis to obtain their objective. This single theory will normally accommodate a specific bidding strategy. In this research a system has been developed to combine bidding models using the theories of utility, probability and present value concepts so that different types of bidding strategies can be accommodated. The developed bidding system is called the Integrated Construction Bidding System.

A bidding model which uses utility theory to evaluate numerous bidding criteria has been developed. The bidding model allows numerical input for criteria which are easily defined and subjective input for criteria which are difficult to quantify. Utility functions are developed for each bidding criterion and these are combined using scaling factors. The combined utility of the bidding criterion is transformed into a bid markup using a markup utility function.

An extension to an existing cash flow model has been performed along with a Monte Carlo study for the sensitivity of the cash flow model.

The Integrated Construction Bidding System has been automated and linked with an information management system to enhance it's usability.

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List of Symbols

a = constant.

ABS = absolute value.

Avge = average.

b = constant.

B/C = bid to cost estimate ratio.

BC71 = basic compiler version 7.1.

C = cost estimate of project.

C/C = cost estimate to average cost estimate ratio.

CCM = cummulative cost multiplier.

CDF = cummulative distribution function.

$E(x)$ = expected amount of profit from bid x.

EP = expected profit.

EV = expected value.

Eu_j = expected utility value of project i.

Eu_p = expected utility value of most preferred case scenario.

Eu_t = expected utility value of threshold or neutral scenario.

Eu_w = expected utility value of worst case scenario.

FaRM = Fair and Reasonable Markup.

FBC = firm's bid to cost estimate ratio.

H0OH = home office overhead.

ICBS = Integrated Construction Bidding System.

IOH = indirect overhead.

ISAM = Indexed Sequential Access Method

L = lower limit of triangular distribution.

LBC = lowest competitor bid.

M = mode of triangular distribution.

$M(Eu_i)$ = markup utility function using expected utility of project i.

$m(t)$ = number of jobs at time t.

M_c = markup produced from the cash flow model.

M_p = markup produced from the probability model (Carr 1982).

M_u = markup produced from the utility theory model.

MRA = multiple regression analysis.

P = amount of a bid.

(p) = probability of winning contract.

p_A = probability of defeating competitor A.

$P(x)$ = proability that bid x will be lowest.

PDF = probability distribution function.

PRB = payroll burden.

PV = present value factor.

$PVin$ = present value of cash inflow.

$PVout$ = present value of cash outflow.

RRR = required rate of return.

S = bid to cost estimate ratio.

S_j = adjusted sclaing factor for bidding criteria j.

U = upper limit of triangular distribution.

$u_j(y_j)$ = utility function for criteria j with option selection y.

$U_j(y_j)$ = common scale utility function for criteria j with option selection y.

VT = volume time function.

$V(t)$ = current volume of work on hand at time t.

W_c = weighting factor to be applied to the cash flow model markup.

W_j = scaling factor for bidding criteria j.

W_p = weighting factor to be applied to the probability model (Carr 1982) markup.

W_u = weighting factor to be applied to the utility theory model markup.

WV = work volume.

x = bid amount.

y = period number.

y_L = lower limit for bidding criteria.

y_M = most preferred point for bidding criteria.

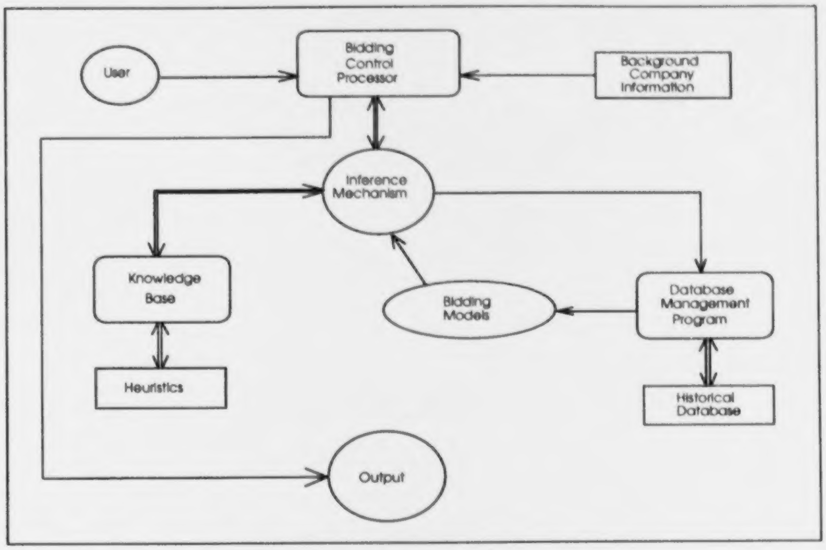
y_T = threshold point for bidding criteria.

y_U = upper limit for bidding criteria.

Chapter 1: Introduction

Competitive bidding in the present construction market is the livelihood of most companies involved in the industry. To achieve a competitive edge in the bidding process many companies have adopted analytical techniques to derive the markup on a construction tender. Typically, these analytical techniques are based on one analysis methodology (e.g. probabilistic, present value, or utility theory) which have been developed into bidding models. Each of these bidding models has limitations usually caused by assumptions required to validate the application of the analyzing theory. The different theories used in the bidding models are generally applicable to the specific bidding strategies of a company. The models using probability theory satisfy a strategy of developing a bid markup based on the competitive environment only. The present value concept models satisfy a bidding strategy that is based on determining a bid markup from internal company requirements. The utility theory model satisfies a strategy of developing a bid markup based on subjective satisfaction of project company criteria only. None of the three modeling techniques will accommodate a bidding strategy which is a combination of two or more of the above bidding strategies. In this thesis, a bidding system has been developed to integrate the three different theories of analysis to obtain a bid markup and hence accommodate most bidding strategies a company can adopt. This bidding system is called Integrated Construction Bidding System (ICBS).

The conceptual structure of the ICBS is shown in Figure 1-1 where various components of the system are identified. The *user* component of the structure represents the interface of the system with an estimator using ICBS. The background company information component represents a data file containing information on the company's bidding policy, expectations, annual forecasts of market share, and current work volume.



User
Bidding Control Processor
Background Company Information
Inference Mechanism
Knowledge Base
Heuristics
Bidding Models
Database Management Program
Historical Database
Output

Figure 1-1: Integrated Construction Bidding System

The system uses three bidding models each of which can determine a markup that is based on either probability theory, present value concept, or utility theory. The probability model requires historical bidding data to represent competitors' bidding behaviors determined from a distribution of bid to cost ratios. The present value model requires the project cash flow and a required return on investment expected by the company. The utility theory model requires subjective and numerical input for various bidding criteria related to the tender project, company policy, and bidding environment. The use of a probabilistic bidding model requires the support of an information management system to supply historical data required by the model. All three models require company policy information and specific information on the tender project. The markups obtained individually from the bidding models are combined using one of two approaches. The first approach is to apply weighting factors which have been derived based on the relative importance of the three model assumptions. The weighting factors are derived from a user's preferences which for the purpose of this research, are directly specified by the user. The second approach to combine the results of the bidding models is to apply a set of rules which basis its result on the magnitude of each markup and the strategy it represents. The *knowledge base* and *heuristics* components of Figure 1-1 contain the features for both approaches of combining the results of the three bidding models. Enhancement of these components will be completed in a future study.

ICBS can be separated into three different modules: an expert system module, an information management system module, and an integration module. The information management system module was previously developed [AbouRizk et al (1993)], and has been incorporated into the bidding system. This module contains a database of public tender openings with the bidders and their bid prices listed for each project. The module also has the updating and retrieval facilities required to maintain and use the database. The expert system module contains rules and a decision tree of how the results of the bidding models are combined. For example, if greater consideration is to be given to the bidding environment than to the internal requirements of the company then a higher preference will be given to the probability theory model over the present value concept model. The two technologies of expert systems and information management are integrated using an integration module which is composed of the components shown in Figure 1-2.

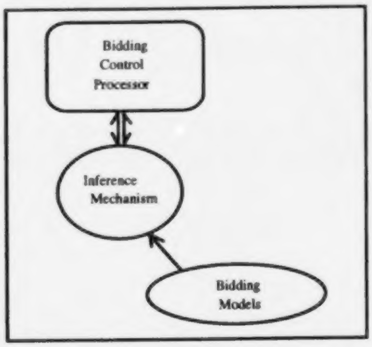


Figure 1-2: Integration module

The Integration module is composed of three components: *bidding control processor, bidding models,* and the *inference mechanism*. This module interacts with the user and a company background file to obtain information and input required by all the modules of the bidding system.

The bidding control processor performs the function of the user interface and sorting of some user input information along with recording and updating information on the user's company so that repetitive input is not required. This component will also invoke the inference mechanism which interprets all information to send to other modules of the system. The bidding control processor receives the analyzed information and advice from the inference mechanism and returns the interpretation to the user as the output component of the module.

The bidding model component is a collection of three bidding models. In this component the historical data and other user input can be analyzed. All data required by the bidding models is received from the information management program, user, background file and the results of the bidding models are returned to the inference mechanism. The bidding models are considered a part of the integration module of the system since they are neither classified as part of the information management system nor do they fall into the area of expert systems.

The inference mechanism is the component at the center of the system and is responsible for a major portion of the integration process. Typically this component is considered part of the expert system but for the ICBS it must be modified to enhance the communication and interaction between all of the modules.

1.1 Objectives

This research develops a construction bidding system that integrates state-of-the-art in construction bidding. This is accomplished by achieving multiple sub-objectives as follows:

- Develop the bidding models component of the integration module. This includes:
    1. Selecting a bidding model which uses probability theory to determine a bid markup.
    2. Extending the present value analysis model of Farid and Boyer (1985) and perform a sensitivity analysis on the input variables.
    3. Developing a new bidding model which uses utility theory and accepts subjective and numerical input to determine a bid markup.
- Study and document existing literature and state of the art in construction bidding.
- Identify various bidding criteria.
- Conceptualize the combination of the results of several bidding models.
- Develop a prototype system.
- Conceptualize the integration of expert system and information management technology.

1.2 Thesis Organization

Chapter 2 discusses the development of bidding models and strategies. It includes discussions on construction bidding literature and the selection of theory and models to be included in ICBS. In Chapter 3 an extension of the bidding model developed by Farid and Boyer (1985) is described, the results and a sensitivity analysis on the revised model are discussed. In Chapter 4, a utility theory model is developed using multi-criteria decision analysis to produce a bid markup for a particular construction tender. In Chapter 5 the methods for combining the results of the bidding models is described and the implementation of the prototype system is discussed. The bidding models selected to be automated in ICBS include the Carr model (1982), and the models described in Chapters 3 and 4. In Chapter 6 concluding remarks and future research are presented.

Chapter 2: Literature Review and State of the Art of Construction Bidding

2.1 Introduction

The construction industry is a unique environment where individual companies earn revenues from the performance of contracts with owners for construction services. Contracts are typically formed by two methods, negotiated or competitively bid. In the negotiated environment an owner approaches the contractor with a project and a price is negotiated. In the competitive bidding environment the contractor submits a closed bid price to an owner who selects a contractor based on the bid submitted (typically lowest). In this chapter the competitive bidding environment and the general procedure for preparing a construction bid are discussed. A review of previous research is summarized to identify the state of the art and select the bidding models to be implemented in ICBS.

2.2 Discussion of Competitive Bidding

Competitive bidding is generally carried out by the following procedure:

1. Owner requests tenders to complete his project.
2. Contracting company decides to bid or not to bid.
3. If company decides to bid, a cost estimate for the project is prepared.
4. Company puts a markup on the cost estimate to recover home office costs and produce a profit.
5. Completed bids are then submitted to owner.
6. Lowest bidder is typically awarded the contract.

The development of the bid for a project is composed of the elements shown in Figure 2-1.

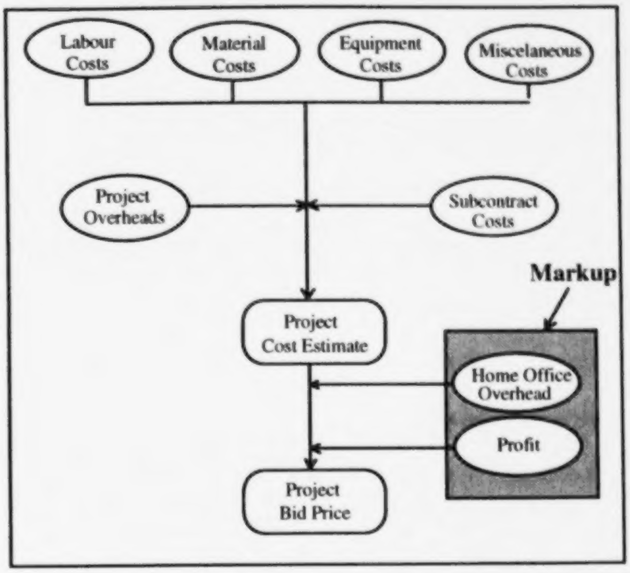

Labour Costs
Material Costs
Equipment Costs
Miscelaneous Costs
Project Overheads
Subcontract Costs
Markup
Project Cost Estimate
Home Office Overhead
Profit
Project Bid Price

Figure 2-1: Preparation of a construction bid

Most contracting firms use similar construction methods and therefore the cost estimate of two different firms will be similar, provided a firm does not make an error in estimating. The markup of the bid is required to cover a contracting firm's home office overhead costs and profit from the project. The nature of competitive bidding involves two contradictory objectives:

- Bid high enough to make a profit.
- Bid low enough to win the project contract.

The determination of an optimal project markup is crucial for construction companies. It may be determined by using sophisticated mathematical techniques or subjective 'gut feeling'. Various mathematical models and bidding systems/strategies have been developed to assist a contracting company in determining an optimal project markup.

2.2 Mathematical Models and Bidding Strategies

Friedman's Model (1956), *"A Competitive Bidding Strategy"*, is a historic landmark in the application of operations research tools to the area of competitive bidding and is used as a datum and standard for other bidding models. Friedman's bidding model determines the optimum bid in a closed competitive bidding environment. The model has been developed for two unique bidding situations: a company bidding on a single project, and a company bidding on several projects simultaneously.

To develop *"A Competitive Bidding Strategy"*, Friedman adopts the strategic objective *"to maximize total expected profit"*. Friedman's model refers to previous tender results of the competition to ascertain a bidding pattern which the competition tends to follow. In a review of historical bidding data, Friedman studied the variances between actual project costs and project cost estimates to determine the bias and variability of a company's cost estimate. A formula for expected profit on a project is derived which incorporates the probability of winning using a bid amount as shown in equation 2.1.

$$E(x) = \int_0^\infty P(x)[x - SC]h(S)dS \tag{2.1}$$

where:

x = bid amount for contract
$P(x)$ = probability that x will be lowest bid
C = cost estimate of project
S = bid to cost estimate ratio
$h(S)dS$ is the probability that actual to estimated cost ratio is between S and $S+dS$

Friedman plots the *'expected amount of profit'* against *'amount bid'* based on a probability of winning the project and produces a curve where the optimum bid is identified as shown in Figure 2-2.

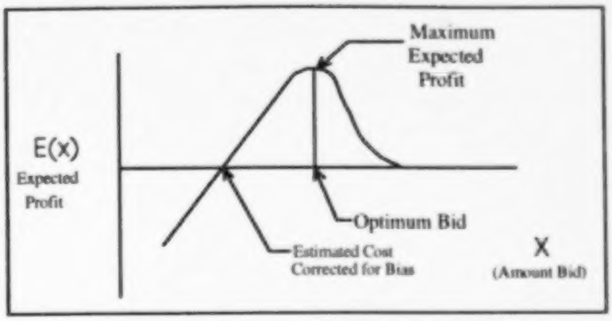


Figure 2-2: Expected profit curve

Friedman discusses the method of determining the probability of winning by using past project bidding data to determine competitors bidding patterns. Probability distributions are formulated for each competitor resulting in a function of their bidding behavior. The probability distributions are then standardized by the company's cost estimates defined by the ratio, bid/cost estimate (B/C). The probability of a company's bid being lower than the competitor is the area enclosed beneath the competitor's probability distribution function and to the right of the B/C ratio. To combine the probability of winning, Friedman suggests that the total probability is the product of all individual competitor probabilities.

Friedman discusses a solution for two different bidding scenarios, one where the number of bidders is known and second where the number of bidders is unknown. A different analysis method has been suggested for each. Also, when a company has several tenders to submit but does not have the capacity to bid on all, Friedman suggests a comparative analysis using dynamic programming.

The Gates' Model (1967), helps in predicting the optimum bid markup on a project. It is based on the main objective of 'maximizing profit'. The model can be applied to several bidding environments which include:

- Lone Bidder strategy.
- Two-bidder strategy.

- Many bidders strategy.
- All bidders known strategy.
- Number of bidders known strategy.
- Least spread strategy.
- Unbalanced bidding strategy.

Each strategy differs slightly but each uses the objective of maximizing the expected value *(EV)*, which is determined by equation 2.2 where *(p)* is the probability of winning a bid and *P* is the amount of the bid.

$$EV = (p)P \tag{2.2}$$

Gates recommends a formula for combining the individual probabilities of winning over various competitors to obtain a single probability. The formula, shown in equation 2.3, is used to combine these probabilities.

$$(p) = \frac{1}{\frac{1-(p_A)}{(p_A)} + \frac{1-(p_B)}{(p_B)} + \ldots + \frac{1-(p_n)}{(p_n)}} \tag{2.3}$$

where:

p_A = probability of beating competitor *A* etc.
(p) = combined probability of defeating all competitors.

In this model the *EV* equation of a project is maximized by setting the first derivative with respect to B/C equal to zero to obtain the optimum markup for the bid.

A comparison of the techniques was conducted by Gates (1976), in which Monte Carlo experiments were performed on both the Gates model (1967) and the Friedman model (1956). Five different groups of experiments and one modification were run three times. The results of the simulations favour the Gates model. The results of the experiment also show that Friedman's model provides inaccurate results when there is more than one competitor.

Harris and Wade (1976), devised a bidding model, *"LOMARK: A Bidding Strategy"*, for use by small to medium sized construction firms to assess the local competitive environment and relate this information to future bidding strategies. LOMARK predicts expected profit and suggests an optimum bid markup given the estimated cost. The method is similar to Friedman's model except no independence between individual contractor's bids is assumed. The LOMARK procedure can be summarized as follows:

1. Collect and arrange cost estimates of past jobs and competitors bids.
2. List competitors in order of competitiveness (target strategy to these firms).
3. Determine probability curve *B/C* ratio for the high ranking competitors in the local market and determine probability of beating these competitors. Estimate probability of competition submitting bids.
4. Generate expected profit *(EP)* curve and graphically determine optimal markup using equation 2.4.

$$EP = P(win)(B / C - 1) \tag{2.4}$$

Harris and Wade applied the model in a real world environment with successful results. The method requires the input of subjective judgment from the bidder in the evaluation of the competitive market, and recommendations are strongly based on subjective judgment. Automation of the model is highly recommended to analyze the competitor's previous bid data since the model is susceptible to errors and omissions in the evaluation of the local market and this influences the reliability of the models results.

Carr and Sandahl (1978) developed a model which uses multiple regression analysis (MRA) to assist a contractor in the bid/no bid decision and in the project markup decision. The model uses the Bid to Cost (B/C) ratio (competitor's bid/ contractor's cost estimate) and the lowest competitor bid to contractors cost ratio (LBC) as key variables in the analysis of historical data. The regression analysis yields the linear equation 2.5, which is used to predict the LBC on a project.

$$\mathrm{LBC}_{\mathrm{pred}} = a + \sum_{i=1}^{n} b_i X_i \tag{2.5}$$

where:

a = sample estimate of the population constant.
b_j = sample estimate of partial regression coefficient.
X_j = an independent variable.
LBC_{pred} = lowest competitor bid to cost ratio predicted.

The LBC predicted by the equation estimates the mean of the LBC distribution which is assumed to be normal. Results from previous construction tenders bid by the contractor are gathered and the LBC distribution determined. The distribution is analyzed with a multiple regression analysis to produce the standard error of the distribution and evaluate 'a' and 'b_i'. The probability of the company's bid price being below the LBC is determined from the area below the LBC distribution and to the right of the companies bid to cost estimate ratio. The expected value from a project bid is then calculated by the product of bid markup and probability of winning. As in previous models the objective is to maximize the expected value.

Sugrue (1980) presents a bidding model, *"An Optimum Bid Approximation Model"*, that eliminates the use of computations to determine an optimum bid markup. The model estimates the markup based on the mean and the standard deviation for the distribution of competitor Bid/Cost ratios which is assumed to be normal. The objective of the model is to maximize profit without using mathematical models that require complex calculations. If the historical bidding data supports the normal distribution, then this procedure does provide a quick approximation for an optimum bid markup.

Ringwald (1982) presents a bidding model for determining a bid markup using the capacity of a company and the length of a project. The capacity of a company is measured in *available crew time* within a calendar period. In this analysis the consideration of resource constraints is used to determine a bid markup.

The procedure for the bidding model can be summarized as follows:

1. Calculate unit of measure for the production year (crew-days).
2. Determine target markup for annum, include overheads and return on investment policy.
3. Determine the target markup per crew-day ratio.
4. Apply ratio to projects by multiplying projects crew-days required.

The markup ratio is applicable for all projects and would not have to be recalculated until the following year or if a change in climatic conditions occurs.

The Carr Model (1982), *"General Bidding Model"*, is a probability based bidding model which extends the previous models (Friedman and Gates) by reducing some of the limiting assumptions. Some of these assumptions are reduced by using standardized distributions of cost estimate and bid to cost ratios to produce the probability of winning. Carr's general formula for the probability of being the low bidder on a project is shown in equation 2.6.

$$P(LBC_{ik} > b) = \int_{-\infty}^{\infty} f(C_i') \left[\int_{bC_i'}^{\infty} f(B_a')dx \right]^{n_k} dx \qquad (2.6)$$

where:

$P(LBC_{ik.b})$ = probability of the project bid being less than the lowest bid cost ratio of competitor i on project k.

$f(C'_i)$ and $f(B'_a)$ = independant standardized distributions of cost estimate and bid to cost.

b = bid amount

n_k = number of competitors bidding on project k

After the probability of winning a project has been determined using a specified bid amount, the expected value (income) of the project is determined using equation 2.7.

$$E(v) = (FBC_i - 1)P(LBC_i > FBC_i)C_i \qquad (2.7)$$

where:

$E(v)$ = expected value using bid v.

$P(LBC>FBC)$ = probability of lowest contractor bid/cost ratio is greater than the firm's bid/cost ratio.

FBC = firm's bid to cost ratio.

C_i = cost estimate.

The bid price is adjusted then the expected value and the probability of winning are recalculated. The optimum bid price is selected as the price which returns the highest expected value.

Carr's procedure for determining the optimum bid price for specified competitors is summarized in the following steps:

1. Determine cost estimate/mean cost estimate (C/C) distribution.

2. For each competitor determine the contractors bid/company cost estimate (B/C) distribution.
3. Find area under C/C.
4. Select bid amount, find probability of winning project using equation 2.6.
5. Standardize distributions with standard deviation of each distribution.
6. Combine probabilities (Friedman or Gates method) of competitors.
7. Calculate expected value from equation 2.7.
8. Adjust bid price and repeat from step 4 and maximize expected value..

The procedure for competing against average competitors is similar. Carr documents a sensitivity study on the three models and found that Friedman's model is less sensitive to changes in the recommended markups than Gates model, which in turn is less sensitive than Carr's model.

Farid and Boyer (1985) developed a bidding model called "*Fair and Reasonable Markup (FaRM) Pricing Model*". This model determines a project markup based on a specified required rate of return (RRR). FaRM considers the project cash flow schedule of a project and uses the present value analysis in determining the recommended markup. The cost per period is determined from the project cost curve and the present value of the cash outflows and inflows is calculated for the total project. The summation of present value of cash inflows and outflows differs by the time lag involved in the contract payment policy. The recommended project markup is derived from the ratio of present value of cash outflows to present value of cash inflows.

Carr (1987) developed a graphical technique which determines the optimum project markup for a construction bid from either *a lowest opposing bid model* or an *average bidder model.* The term *optimum* is defined as the trial markup which produces the highest expected gross profit on a project. The expected markup presented by Carr in equation 2.8:

$$E(V) = P(W)E(V / W) = P(W)(FBC - 1)C \tag{2.8}$$

where:

$E(V/W)$ = the expected value (gross profit).
$E(V)$ = expected value in excess of project cost.
$P(W)$ = probability of winning.
FBC = firm's bid to cost ratio.
C = firm's cost estimate.

The direct solution method for determining the optimal markup maximizes equation 2.8 by differentiating the firm's bid to cost estimate ratio and setting derivative equal to zero. This model is different from typical bidding models since it utilizes the lowest bid to cost estimate ratio distribution which is the inverse of the probability of winning at a given markup.

Ahmad and Minkarah (1987) developed a procedure called *"Optimal mark-up for bidding: a preference-uncertainty trade off approach"* which determines the markup for a competitive construction bidding environment using multi-dimensional utility theory.

The model divides markup into three separate uni-dimensional utility functions which are overhead, loss, and profit. Each function is described by the general exponential equation:

$$u = \alpha + \beta e^{-\gamma x} \tag{2.9}$$

The three uni-dimensional utility functions are combined to form a single utility curve using a weighting factor *k* as shown in Figure 2-3.

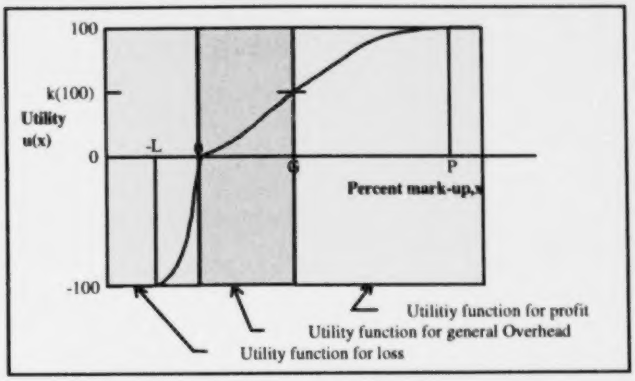


Figure 2-3: Combined single utility curve

The single utility function is transformed into an expected utility function by integrating the exponential utility function over probability distribution functions of historical data which are assumed to be normal. The optimum markup is then selected from this final expected utility function which is plotted in Figure 2-4.

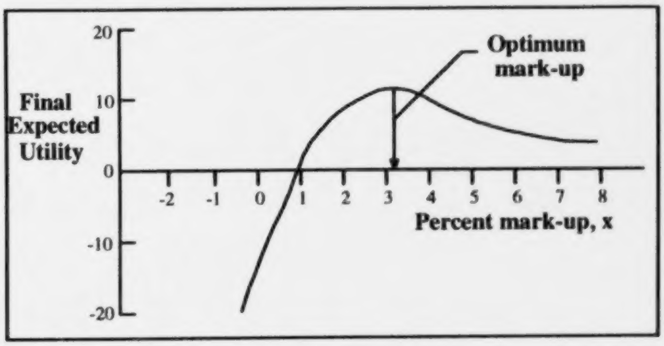


Figure 2-4: Final expected utility function

The model returns a higher markup when the importance of general overhead is rated low and a lower markup when general overhead importance is rated high. As one expects, when a contractor's overhead costs are high, the need to recover overhead is high and the need to win the project is high.

Griffis Model (1992) is a method to improve the determination of probability of winning a project. Griffis suggests that the static distribution describing a competitor's bidding behavior can be improved by maintaining a *volume-time* function for each of the company's competitors. Griffis has found that the volume of work on hand is a major influence on the decisions a contractor makes on a specific tender call and therefore these should be considered when describing a competitor's bidding behavior. The workload diagram of a contractor can be represented by a volume-time (VT) function as shown in equation 2.10 for current volume of work on hand *V(t)*.

$$V(t) = \sum_{k=1}^{m(t)} (\alpha_k t + \beta_k) \tag{2.10}$$

where:

$m(t)$ = the number of jobs on hand at time t.
$\alpha_k t + \beta_k$ = equation of the *kth* job.

Griffis' model further develops the distribution of bid to cost ratio and incorporates the volume-time function as a parameter and then maximizes an expected return function similar to previous models.

2.3 Applied Bidding Systems and Industry Surveys

Morin and Clough (1969) developed a mathematical model, *"OPBID: Competitive Bidding Strategy Model"*, to assist a contractor in maximizing profits when bidding on *lump-sum* contracts. The model was automated so that contractors can use it without limited knowledge of probability theory. The model is based on the cost estimate of a project which is used to calculate B/C ratios that are used in the analysis of the competition. The bidding model emphasizes six elements which investigate the competitive bidding environment that may impact on the bid markup which are:

1. Cost estimate
2. True cost
3. Markup
4. Number of competitors
5. Identity of competitors
6. Class of work (heavy, industrial etc.)

The model is applied to a series of project tenders and the total expected profit is found from the sum of individual expected profits. The equation for expected profit from a project is similar to previous models and includes the variables for probability of winning, office overheads, cost estimate and project markup. The optimum markup is determined by maximizing the expected profit which is calculated by setting the first derivative equal to zero and implementing an iterative procedure.

OPBID was one of the early applications of a mathematical bidding model coded into a computer program and implemented by a contractor.

Anaheim Technologies (1987) developed an expert system called, *"Anaheim Bid"*, to perform the function of computing an optimum markup on a given project. The model uses a constant cumulative distribution function as a basis for the markup and then applies the appropriate risk and exposure factors to modify and determine the final markup. The system uses the concept of 'fuzzy set theory' to determine the impact of risk variables on bid markup. The method is simple to use since it requires linguistic variables as input. The system does not record, analyze or manipulate historical bidding data to determine the behavior of competitors, but asks the user to do this procedure prior to using *Anaheim Bid* and input the results. Another system is needed to perform this function for effective use of the bidding system.

Ahmad and Minkarah (1988) conducted an industry survey (*"Questionnaire Survey on Bidding in Construction"*) to assist in determining the bidding factors considered by construction companies. The response to the questionnaire was obtained from the top 400 general contractors in the United States.

Some of the findings of the survey are:

1. In both the bid/no bid and percent markup decisions other factors are considered to be more important than profitability and competition.
2. Most contractors use only experience, judgment and subjective assessment to make bid decisions.
3. General contractors are heavily reliant on subcontractors and an effort is made to keep a good relationship with such firms.
4. The time allowed to prepare a bid and the quality of the design are important factors which affect the contract bid price.
5. The client/owner relationship is a high priority to the general contractor.
6. Prestige and public exposure is a quality consideration to protect and enhance a firm's reputation.
7. Contractors generally prefer negotiated work over competitive bidding.
8. The ranking of factors for the two bidding decisions considered are different.

The ranking of the factors by respondents for the percent markup decision are as follows (Top 5):

1. Degree of hazard
2. Degree of difficulty
3. Type of job
4. Uncertainty in estimate
5. Historic profit

The survey also determined whether the firm was currently using some type of statistical/mathematical analysis to asses the competition and approximately 80% of the respondents said 'no'. When asked if they are pleased with their current bidding methodology nearly 75% of the respondents replied 'yes'. However, 66% of those who said 'no', obtain more than 50% of their work through competitive bidding as compared to negotiated work.

The survey helps identify and order the factors to be considered in the bid/no bid decision and the percent markup decision. The survey also identified that few firm's use statistical methods to analyze the competition, but the firm's that use a mathematical approach rely mostly on the competitive bidding environment.

Tavakoli and Utomo (1989) have developed a knowledge based expert system which determines the bid markup on a construction bid. The expertise modeled in the system is collected from an interview with an industry expert and from previous construction literature. The system is a prototype that was developed using a production rule language INSIGHT 2+ to transfer the experts knowledge into a system.

The system determines the markup consisting of the overhead and profit. The base overhead is calculated from expected annual overhead over the expected annual work volume ratio which is multiplied by a correcting factor. The base profit is calculated from the expected annual profit over the expected annual work volume ratio which is also multiplied by another correcting factor. The recommended markup is simply the sum of the base overhead and the base profit. The input for the parameters of the system is a numeric scale from 0 to 100 with a value of 100 referring to high confidence and zero to no confidence. The confidence levels input are used to determine the value of the correcting factors to be applied to the base profit and overhead.

2.4 Discussion of Bidding Models

Many authors discuss bidding models developed by others and comment on the applications, limitations and validity of the assumptions of these models.

Fuerst (1976) discusses the formula used in Gates' model that combines the probability of winning over several competitors. Fuerst shows that proofs performed by others to support Gates' model are incorrect due to assumptions of independent events and that their validity can be obtained only by drawing the bids of all the competitors from the same probability density function. Other proofs change the meaning of probability of winning, to probability of defeating a competitor given that the competitor is low bidder.

Feurst also suggests that very few bidding models explicitly consider the uncertainty of the cost estimate and are therefore susceptible to the notion of variation in bids due to variation in cost estimates. A formula for standardizing the cost estimates for a contractor is given by using a comparison with past actual costs and cost estimates.

King and Mercer (1987) discuss the validity of assumptions used in the bidding models by Friedman (1956), Gates (1967) and Carr (1982). Past controversy over the validity of Friedman's model versus Gates' model has typically criticized Gates' for his formulas and Friedman for his assumptions. However, it is noted by King and Mercer that the assumptions used in Friedman's model are implicitly used in Gates' model and therefore the criticism of Friedman's model apply to both.

The main theme of the bidding models is that the bidding strategy of competitors is described by a fixed bidding pattern with constant parameters. The formula used in Gates' model requires a modification to the definition for the variable of *probability of beating a competitor,* which is changed to *probability of beating a competitor given that the competitor wins.* The modification of the variable definition gives acceptable results. It is further discussed that both Friedman's and Gates' models give the probability of winning a project and do not consider the long term effect of random bidding. Friedman's model is specified to be adaptable to the long term effect of bidding by using the long term probability of winning several contracts with a specified distribution of markups rather than the probability of winning a specific contract at a specific markup.

King and Mercer (1987) also discuss Carr's model (1982), and suggests that the model is free of restrictive assumptions. The analysis performed in his model centers on large variations in a bidders' cost estimates, but the model implicitly uses the assumptions in Friedman's model since the expected profit is used as the single objective and competitors bid from random distributions with constant parameters. Further similarities to Friedman's model are that the probability of winning is determined by a series of integrals which involve the product of probability density functions for the companies standardized costs and competitors bids thus the assumption of variables are statistically independent. The assumption of a companies standardized markups are independent, is a criticism which also applies to Carr's model.

King and Mercer summarize the four main assumptions which are used to some extent by all the bidding models that have been discussed:

1. There is a single objective measure to maximize.
2. There is an ample supply of competitive information.
3. Competitors will continue to bid as they have in the past.
4. Competitors bid randomly from distributions with constant parameters.

Ioannou (1988) discusses the validity of past bidding models with arguments based on symmetry of the bidding problem. The known variables in a bidding situation are the cost estimate for the project and the bid amount to be submitted. The unknown variable is whether or not the bid will be low. The objective of any bidding model is to help select an optimum bid price (or markup). In probability based bidding models the most important random variable is the minimum Bid/Cost ratio of all the competitors since the probability of winning is found from the compliment of the cumulative distribution function of minimum B/C. The probability density function of B/C for the competition is a difficult and controversial objective for any bidding model as assumptions are required to make its application valid. In Friedman's model the following two assumptions are made:

1. Probability distribution of each competitor's B/C ratio is independent of the firm's cost estimate and selected B/C for the project.
2. Competitor's B/C ratios are mutually independent of each other.

Ioannou states that these assumptions avoid common sense since the cost estimate of a project will indicate the range of competitors' bid prices for the probability distribution (assumption 1), and secondly if one competitor knows the markup or actual bid price of another competitor his bid price will be adjusted accordingly (assumption 2). Therefore the validity of the assumptions used by Friedman are suspect. However, Friedman standardized the variables using the cost estimate of the project and based his model on the standardized probability distribution (B/C), thus the common sense dependencies are resolved. The use of the cost estimate to calculate the competitor's B/C ratio results in a functional dependency but not a probabilistic dependency.

Ioannou proposes that where the cost estimates of past projects are unavailable, the *engineer's estimate* can be substituted and the bidding model can be applied.

Ioannou discusses previous arguments based on symmetry which are false and proves that the common sense approach for combining the probability of winning over several competitors is inadequate and that Friedman's method is correct.

Common sense approach: $P(low) = 1/(n+1)$

Friedman: $P(low) = P(avge)^n$

where n = number of competitors

These arguments ignore the state of information that is non symmetric on which each probability distribution is derived. In order for the symmetry argument to be valid, a firm cannot have any knowledge of competitors previous bidding history (in this case Freedman's assumptions are incorrect). Other possibilities of correct application of the symmetry arguments is that all contractors have the same cost estimate but do know other firm's markup ratios, and all contractors have the same markup ratio but this value is unknown. In these applications, the Friedman's assumptions will lead to the same conclusion as the common sense approach but the common sense approach can only be valid for these special bidding situations that are highly unlikely.

2.5 State of the Art Discussion

Considerable work has been done in the area of bidding strategy models and systems, however, most research uses the procedures developed by Friedman (1956) and attempts to modify some of the assumptions which he used in developing the landmark mathematical model. Gates' model used similar approaches to the problem but the main difference in combining probabilities of defeating several competitors.

The current state of the art in probability based bidding models is summarized by Griffis (1992). Competitor's bidding behavior is described by the historical data and a competitor's past bids are compared to a contractors past cost estimates to determine a B/C ratio which is used to develop the competitor's histogram. The function for probability of winning over a particular competitor is determined by integrating the competitor's relative-frequency histogram. An expected profit function of a project for the contractor's specific bid is determined by multiplying the probability of winning function by the competitor's B/C minus one. If more than one competitor exists, the probability of winning over each competitor is determined if sufficient historical bidding data is available to determine a cumulative relative-frequency histogram. The individual probability functions are combined according to the methodology of Friedman (product of individual probabilities) or Gates (inverse of $\sum \frac{1-P(A_i)}{P(A_i)}$). If sufficient data to describe the competitor's bidding behavior is not available then the "average" bidder methodology described by Friedman is used to analyze the competition.

The state-of-the-art for implemented bidding systems is the Anaheim Technologies development of an expert system to determine the optimum bid markup for a project incorporating several risk variables into the model.

The state-of-the-art for utility theory to describe markup is the Ahmad and Minkarah model (1987). Weighting factors are assigned to combine utility functions to form a final utility curve and this allows for the incorporation of risk and project uncertainties.

2.6 Selection of Bidding Models for ICBS

Based on the review of the literature on bidding there appears to be three different philosophies used to resolve the bidding problem; utility theory, probability theory, and time-value of money techniques. The models used by the ICBS include a model for each philosophy.

Carr's model (1982) is selected since it uses a B/C ratio probability distribution model. It was selected over the landmark Friedman and Gates models since it does not have as many limitations as either model and its test results have a greater sensitivity and accuracy than previous models.

Carr's model provides similar analysis as performed by Friedman and Gates models and is therefore open to many of the same criticism as the previous models. Carr's model reduces any bias of the B/C ratio and increases the acceptability of independent bidders by standardizing the variables determined from the B/C ratios using a single standard deviation of the probability distribution. The model has a single objective, *'to maximize profit on a project'*, but this does not simulate the real world bidding strategies of most contractors as illustrated from the survey by Ahmad and Minkarah (1988). This problem is resolved by the ICBS which uses Carr's model as advice on this particular objective which is weighted with respect to other objectives in the bidding problem. The implementation of Carr's model assumes that sufficient historical bidding information is available. To enhance the usability of the model and efficiency of a bidding system an organizational tool is provided (database) that contains all the data used by the bidding model. This feature is provided within ICBS in the information management component. The final criticism is that the model is based on the philosophy that *competitors will bid in the future as they have in the past,* does not consider the position of the competition in the marketplace nor does it consider the competitions present workload. The problem is resolved by ICBS where the workload of the competition bidding on the project is evaluated by other bidding models and considered as a separate objective.

To represent the time-value of money technique in the ICBS, an extension of Farid and Boyer's Model (1985) is developed and described in Chapter 3.

A model using utility theory and incorporating subjective judgment is developed and discussed in Chapter 4.

Chapter 3: Cash Flow Model

3.1 Introduction

A common temptation for a contracting company is to reduce a project bid price moments before the tender closing. Commonly, a bid price is adjusted after reconsidering the project estimate and risk assessment. The effect of any economic factors is normally not considered. As a result of neglecting the cost of financing, many projects result in losses. The proposed cash flow model will provide a minimum project markup which meets the specified criteria of the project.

The application of economic analysis can also be beneficial for *negotiated contracts.* A significant amount of annual work volume for many contracting firms results from negotiated contracts. The use of the cash flow analysis model maintains the required return on a project while a client receives a consistent markup on all negotiated contracts.

3.2 ICBS - Cash Flow Model

The cash flow model concept adopted by ICBS is an extension to the work of Farid and Boyer (1985) and Fondahl and Bacarraza (1972). The markup of a project is determined from equation 3.1 as discussed in Farid and Boyer (1985).

$$\textit{Recommended Markup} = \frac{\sum \textit{(Present Value of Cash Outflow)}}{\sum \textit{(Present Value of Cash Inflow)}} - 1 \qquad (3.1)$$

Existing models assume that project construction costs are uniformly distributed over each payment period (normally one month). This phenomena does not precisely model the *real world* environment. Although the uniform cost assumption is accurate for some cost categories, others occur as discrete events and require an analysis as described in this model. In order to differentiate and apply different types of cost curves, several cost categories must be identified. The present value analysis is applied to the individual cost categories and later is combined to determine a recommended markup. The present value calculations use a given rate of return on investment expected by the contracting firm.

3.3 Information Required by Cash Flow Model

Cash flow analysis model requires information about the specific project as well as details of the contracting firm's business policy. The information required by the model is:

1. Project cost curve (S-curve) by cost category.
2. Indirect overhead charges of a project.
3. Project payment policy.
4. Percent holdback or retainage.
5. Company billing policy.
6. Required rate of return compensating for interest, taxes and profit.
7. Home Office Overhead (HOOH) to be applied to the project.

The listed factors are either derived using company background information or input directly.

3.3.1 Project Cost Curve (S-curve)

The project cumulative cash flow curve or S-curve is a plot of the contracting firm's costs for the project on a cumulative basis. Applying each cost item to the schedule and plotting the cumulative sum with respect to time the S-curve can be formulated as illustrated by the example shown in Figure 3.1.

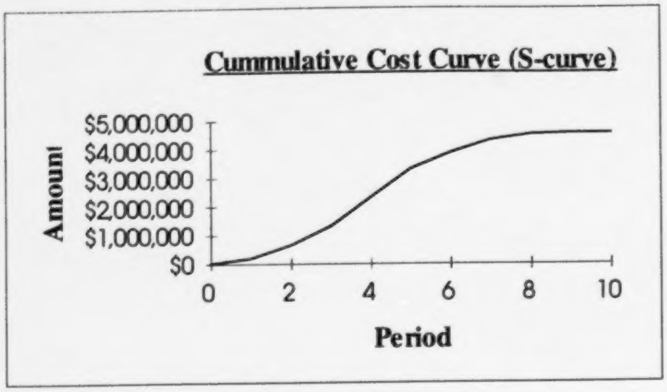


Figure 3-1: Typical S-curve for a project

There are six cost categories in the project cost and they include:

1. Labour costs
2. Payroll burden (PRB)
3. Material costs
4. Equipment costs (eg. rental or ownership)
5. Operating costs (eg. equipment operating)
6. Indirect overhead costs

Each cost category will be represented by a function which best models the cash flow as it would occur on a construction project. For example, the labour costs are paid discretely in 2 week intervals (employee payroll) resulting in a step cumulative cost curve as illustrated by the example shown in Figure 3-2.

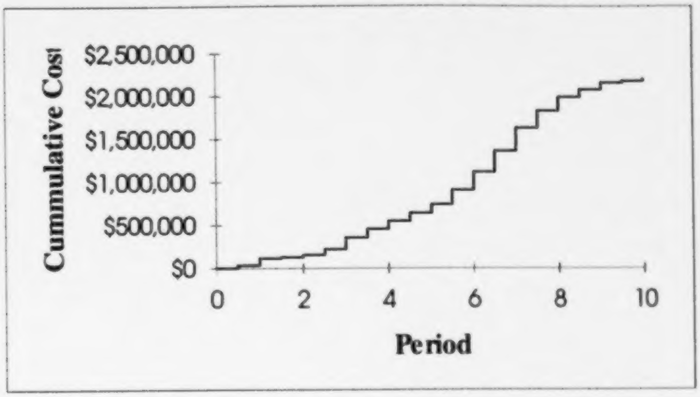


Figure 3-2: Sample cumulative cost curve for labour

The payroll burden of the labour element is incurred at the end of every month (not bimonthly) and therefore the step function representing this cost category can be modeled similar to the example shown in Figure 3-3.

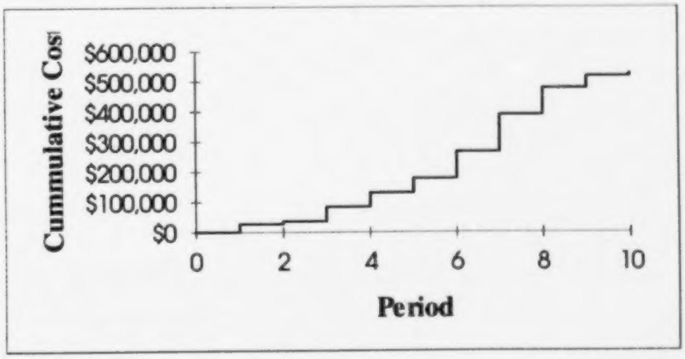


Figure 3-3: Sample cumulative cost curve for payroll burden

The cost of materials can vary depending on the suppliers policies, but normally a supplier will invoice a company for supplied materials at the end of each month and require payment within 10 working days (2 weeks) of receiving the invoice. The material cost category is therefore best represented by the step function as illustrated by the example shown in Figure 3-4.

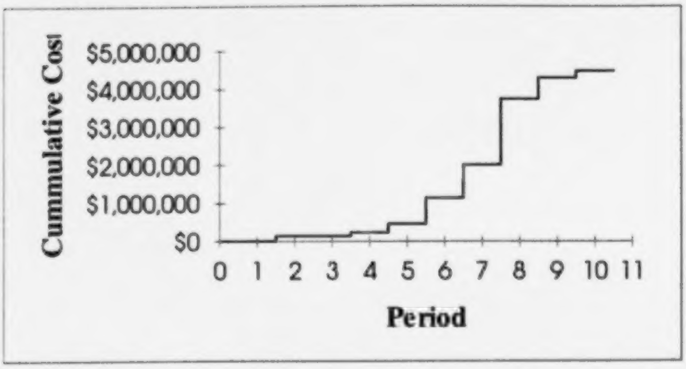


Figure 3-4: Sample cumulative cost curve for materials

Similarly, the cost of equipment rentals will occur within a specified time of receiving a monthly invoice from the rental company. This time-frame is likely to be in the order of 10 working days and therefore the equipment cumulative cost curve will be represented by a step function similar to the material cost category. If equipment is owned by the company, it is assumed that a rental rate covering depreciation and financing is calculated. The company then charges itself for the rental of its own equipment but the charge would be incurred at the end of each period and treated similar to the payroll burden costs of Figure 3-3.

The operating costs of a construction project are occurring on a day to day basis throughout the project and therefore a linear function within each payment period is a suitable representation of the category. Included in the operating cost category are materials which must be paid for when used or required (no credit extended by supplier). The operating costs linear representation is illustrated by the example shown in Figure 3-5.

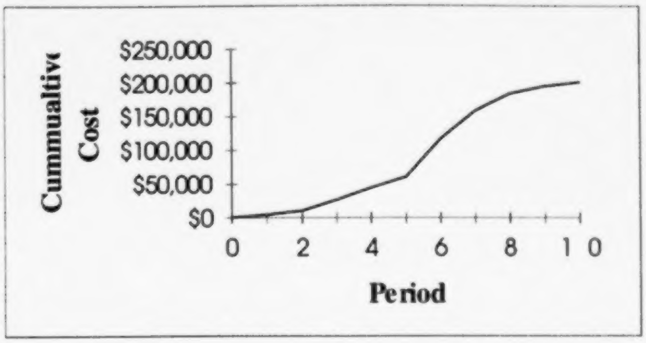


Figure 3-5: Sample cumulative cost curve for operating costs.

The indirect overhead costs of a construction project normally occur at the end of each month throughout the project duration and therefore are best represented by a step function similar to the example for payroll burden costs in Figure 3-3.

This method of determining the S-curve and deriving the cost curves for each of the cost categories is ideal for the application of the cash flow analysis model. The method however assumes that an estimator has prepared a project schedule. This assumption may not be accurate since the company has not been awarded the project and would prefer to keep estimating and bid preparation costs to a minimum. When the schedule is not known, the cost curve can be determined from a normalized S-curve of a similar past project with all costs per period normalized by the total cost of the previous project. This curve can then be translated into costs per category by approximating the percent allocated to each category (i.e. labour approximately 30% of total cost) which can also be determined from the similar past projects constructed by the firm. The approximated multipliers are then used to derive the cost curves for each category from the normalized cost curve and the new project cost estimate. Although this feature for deriving cost curves is available, the accuracy of the model is reduced and thus the previous method of constructing cost curves for each new project is preferred.

3.3.2 Home Office Overhead Charges

The Home Office Overhead (HOOH) charges discussed in this section are company overheads. The company indirect overheads or HOOH are costs incurred by the company that are not directly related to one specific project and therefore they must be distributed over all projects in hand. Such costs would include the overhead of senior management as well as the operating expenses of the head office. The HOOH charges applied to a project are determined from the estimated work volume and indirect overhead expenses of the company which are forecasted annually by the contracting firm's management. The calculation of the estimated *HOOH rate* is similar to the method suggested in Adrian (1982) which represents the *amount of indirect overhead per dollar of project* and is derived form equations 3.2 - 3.4.

$$\textit{Remaining Indirect OverHead} = \textit{Forecasted IOH - Recovered IOH} \tag{3.2}$$

$$\textit{Remaining WorkVolume} = \textit{Forecasted WV - Cumulative WV (annual)} \tag{3.3}$$

$$\textit{Indirect Overhead (HOOH) Rate} = \frac{\textit{Remaining IOH}}{\textit{Remaining WV}} \tag{3.4}$$

In the event that a firm recovers its HOOH at a faster rate than expected, equations 3.4 adjust the rate of HOOH so that the phenomena can be used as a competitive edge for future bids prepared by the firm. If the *Remaining WorkVolume* is equal to zero or the HOOH *rate* is less than zero then the HOOH *rate* is equal to zero for this project bid. The HOOH *rate* is multiplied by the estimated total direct cost of the project to determine the amount of HOOH to apply to the project estimate. The HOOH is evenly distributed to each period of the project.

3.3.3 Other Variables

To be complete the cash flow model should consider all factors with a time-cost relationship. The project payment policy is included in the analysis since it is the time between submittal of an invoice and the receipt of payment which effects the overall cash flow of the project. Another factor with a time-cost relationship is the project holdback or retainage amount held by the owner to ensure payment to all suppliers and sub-trades. Included in this is the time when the holdback is released after performing a contract. Another factor that affects the cash flow on the project is the billing policy factor which is a multiplier that is applied to the progress invoices of a project. The billing factor allows the contractor to incorporate a front or rear end loading policy. The final factor that is considered in a cash flow analysis is the required rate of return on investment specified by the company policies. The required rate of return is the interest rate applied to the project cash flows.

3.4 Methodology of Analysis

In the present value analysis the payment of costs are treated as cash outflows and payments received from the owner are cash inflows. The progress payment invoices are prepared on a monthly basis to determine the amount of expenses the firm incurred during the period. The payment policy factor is used to obtain the cash inflows by the applying the appropriate lag time.

3.4.1 Project Cash Flow

The direct period cost for the six cost categories is derived from the cumulative cost category curve, by determining the difference in two successive payment periods. The HOOH to be charged to the project is evenly distributed over each project period. The cash inflow or progress payment due from the owner per category is determined from the direct period cost using equations 3.5 to 3.7 as recommended by Farid and Boyer (1985).

$$\text{Chargeable Cost (period)} = \text{Direct Cost(period)} - \text{HOOH (period)} \tag{3.5}$$

$$\text{Billable Cost (period)} = \text{Billing Factor} \times \text{Chargeable Cost (period)} \tag{3.6}$$

$$\text{Progress Payment Due (period)} = \text{Billable Cost (period)} \times (1\text{-Holdback}) \tag{3.7}$$

The total progress payment due per period is determined from the summation of equation 3.7 for all the cost categories. The cash outflow for each period is the direct cost which is calculated from the sum all individual category costs for the period. The cash inflow for each period is equal to the total progress payment due but will not be received until after the time lag of the payment policy. A sample cash flow diagram of all cost categories using a normal time lag (10 working days approval and 10 working days for payment) is illustrated by the example shown in Figure 3-6. The project holdback is released by the owner at the specified time following the performance of the project contract as shown in Figure 3-6. In this Figure the holdback is released 1.5 periods (45 days) following the completion of the project.

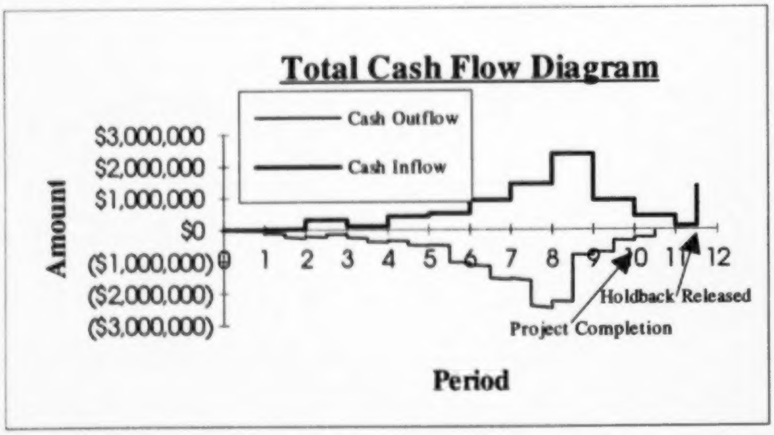


Figure 3-6: Sample cash flow diagram of a construction project

3.4.2 Determination of Markup

The markup is calculated using equation 3.1 with the present value of cash outflow and inflow. The present value factor for each project period (*n*) is applied to the project cash flows starting with period zero which represents project costs incurred prior to the start of the project. The present value factor is derived using equation 3.8 where the required rate of return is substituted for *i%*.

$$\text{Present Value Factor } (P/F, i\%, n) \;=\; \frac{1}{(1 + i\%)^{n}} \qquad (3.8)$$

The sum of the present values of cash outflow and inflow is calculated for all periods and all cost categories of the project. The recommended markup is calculated using equation 3.1 and is applied to the direct project cost along with other project specific indirects such as bond premiums, insurance premiums, and contingencies.

3.5 Example Application

In this section an illustrative example is used to explain the cash flow analysis model. For a specific construction project a cost estimate has been produced and the total direct project cost is $8,901,095. The total direct project cost is separated into the six cost categories per period as shown in Table 3-1. The project start date is September 1, 1992, and a $20,000 cost has been incurred prior to the project start but after the contract was awarded. The total estimated duration of the project is 10 months. Project invoices are submitted on a monthly basis over the 10 month period and the owner takes 10 working days for consultants approval and 10 working days for the owner to make payment to the contractor. The resulting time lag for payment receipt is 20 working days from the time the invoice is submitted. The project holdback is 15% on all progress payments which is to be released 45 days following complete performance of the contract.

The contracting firm has forecasted an annual work volume of $45million and an indirect home office overhead of $200,000. The firm has completed $28million of construction and recovered $145,000 of indirect overhead. The firm 's payroll burden is 24% of the labour cost. The firm has also determined a required rate of return of 2.5% per month and adopts a front load billing policy which increases the first 2 periods (months) of construction by 4%.

The rate of HOOH is derived using equations 3.2-3.4 as follows:

$$\text{Remaining } WV = \text{Forecasted } WV - \text{Cumulative } WV = \$45mil - \$28mil$$
$$\text{Remaining } WV = \$17mil$$

$$\text{Remaining } IOH = \text{Forecasted } IOH - \text{Recovered } IOH = \$200{,}000 - \$145{,}000$$
$$\text{Remaining } IOH = \$55{,}000$$

$$\text{HOOH rate} = \frac{\text{Remaining } IOH}{\text{Remaining } WV} = \frac{55{,}000}{17mil}$$
$$\text{HOOH rate} = \$0.0032 \text{ per } \$ \text{ direct cost}$$

The amount of indirect overhead applied to the project is calculated from the total direct cost estimate times the HOOH rate resulting in the indirect home office overhead amount of $28,798 or $2879.80 per period.

The diagram of cash outflow and inflow for the project was previously shown in Figure 3-6. The project is completed by July, 1993 and the project holdback is released in September, 1993. The present value of cash outflow for the payroll burden, operating costs, and indirect project overhead cost categories is determined in Table 3-2. The present value of cash outflow for material and equipment is calculated in Table 3-3. Categories with costs occurring at the same time are analyzed in the same table.

Table 3-1: Cost per category of project

Date	Period #	Total cost	Labor Costs	Payroll Burden	Material Costs	Equipment (rentals)	Operating Costs	IOH costs
Sep-92	0	$20,000						$20,000
	0.5		$36,000					
Oct-92	1	$359,987	$79,000	$27,600			$4,200	$32,000
	1.5		$15,400		$139,187	$42,000		
Nov-92	2	$123,892	$24,600	$9,600			$6,400	$13,000
	2.5		$68,000		$6,892	$48,000		
Dec-92	3	$483,443	$128,000	$47,040			$16,400	$31,000
	3.5		$104,900		$79,803	$113,200		
Jan-93	4	$606,899	$88,500	$46,416			$17,400	$33,400
	4.5		$94,600		$227,283	$89,000		
Feb-93	5	$1,090,342	$101,800	$47,136			$16,600	$54,000
	5.5		$164,000		$677,506	$98,700		
Mar-93	6	$1,697,241	$204,800	$88,512			$56,000	$74,000
	6.5		$247,900		$869,929	$240,000		
Apr-93	7	$2,787,583	$266,800	$123,528			$41,500	$120,000
	7.5		$201,400		$1,731,855	$256,000		
May-93	8	$1,090,387	$162,000	$87,216			$25,600	$43,000
	8.5		$86,400		$556,871	$14,300		
Jun-93	9	$500,654	$77,100	$39,240			$10,700	$32,000
	9.5		$23,400		$185,414	$69,800		
Jul-93	10	$140,667	$22,300	$10,968			$6,000	$12,000
	10.5				$19,499	$46,500		
	Total	$8,901,095						

Table 3-2: Present value of cash outflow for IOH, PRB and operating costs

Date	Per. #	PRB cost	Operating cost	IOH cost	Total Cost	PV factor	PVout
Sep-92	0	$0.00	$0.00	$20,000.00	$20,000.00	1.00	$20,000.00
Oct-92	1	$27,600.00	$4,200.00	$32,000.00	$63,800.00	0.98	$62,243.90
Nov-92	2	$9,600.00	$6,400.00	$13,000.00	$29,000.00	0.95	$27,602.62
Dec-92	3	$47,040.00	$16,400.00	$31,000.00	$94,440.00	0.93	$87,696.93
Jan-93	4	$46,416.00	$17,400.00	$33,400.00	$97,216.00	0.91	$88,072.90
Feb-93	5	$47,136.00	$16,600.00	$54,000.00	$117,736.00	0.88	$104,061.47
Mar-93	6	$88,512.00	$56,000.00	$74,000.00	$218,512.00	0.86	$188,422.21
Apr-93	7	$123,528.00	$41,500.00	$120,000.00	$285,028.00	0.84	$239,784.15
May-93	8	$87,216.00	$25,600.00	$43,000.00	$155,816.00	0.82	$127,885.45
Jun-93	9	$39,240.00	$10,700.00	$32,000.00	$81,940.00	0.80	$65,611.68
Jul-93	10	$10,968.00	$6,000.00	$12,000.00	$28,968.00	0.78	$22,629.76
						PRB PVsum =	$1,034,011.06

The present value for the cost category of labour is calculated in Table 3-4. The payments made by the owner is the cash inflow and they are made once per payment period. The cash inflow must be adjusted for the home office overhead amount of

$2879.80 per period invoice. The holdback amount must be recovered before applying the present value factor. The calculation of the cash inflow is shown in Table 3-5 and the present value calculation of the cash inflow is shown in Table 3-6.

Table 3-3: Present value of cash outflow for material and equipment

Date	Per. #	Material Costs	Equipment Costs	Total Costs	PV factor	PV(cost)
Sep-92	0					
Oct-92	1.5	$139,187	$42,000.00	$181,187.00	0.96	$174,598.79
Nov-92	2.5	$6892	$48,000.00	$54,892.00	0.94	$51,605.90
Dec-92	3.5	$79803	$113,200.00	$193,003.00	0.92	$177,023.34
Jan-93	4.5	$227283	$89,000.00	$316,283.00	0.89	$283,020.87
Feb-93	5.5	$677506	$98,700.00	$776,206.00	0.87	$677,634.85
Mar-93	6.5	$869929	$240,000.00	$1,109,929.00	0.85	$945,344.44
Apr-93	7.5	$1731855	$256,000.00	$1,987,855.00	0.83	$1,651,793.35
May-93	8.5	$556871	$14,300.00	$571,171.00	0.81	$463,034.44
Jun-93	9.5	$185414	$69,800.00	$255,214.00	0.79	$201,849.54
Jul-93	10.5	$19499	$46,500.00	$65,999.00	0.77	$50,925.67
					Mat.PVsum =	$4,676,831.20

Table 3-4: Present value ofcash outflow for labour

Date	Per. #	Labour Cost	PV factor	PV(Cost)
Sep-92	0			
	0.5	$36,000.00	0.99	$35,558.27
Oct-92	1	$79,000.00	0.98	$77,073.17
	1.5	$15,400.00	0.96	$14,840.03
Nov-92	2	$24,600.00	0.95	$23,414.63
	2.5	$68,000.00	0.94	$63,929.20
Dec-92	3	$128,000.00	0.93	$118,860.72
	3.5	$104,900.00	0.92	$96,214.82
Jan-93	4	$88,500.00	0.91	$80,176.63
	4.5	$94,600.00	0.89	$84,651.32
Feb-93	5	$101,800.00	0.88	$89,976.37
	5.5	$164,000.00	0.87	$143,173.48
Mar-93	6	$204,800.00	0.86	$176,598.40
	6.5	$247,900.00	0.85	$211,140.43
Apr-93	7	$266,800.00	0.84	$224,449.56
	7.5	$201,400.00	0.83	$167,351.83
May-93	8	$162,000.00	0.82	$132,960.94
	8.5	$86,400.00	0.81	$70,042.38
Jun-93	9	$77,100.00	0.80	$61,736.16
	9.5	$23,400.00	0.79	$18,507.13
Jul-93	10	$22,300.00	0.78	$17,420.72
			Labour PVsum =	$1,908,076.21

The total present value of cash outflow is found by summing all outflow present values.

$$\text{Present Value Cash Outflow} = 1908076 + 4676831 + 1034011$$
$$\text{Present Value Cash Outflow} = \$7,618,918$$

Table 3-5: Calculation of cash inflow for total project.

Date	Per #	Total Cost	HOOH cost	Charge Cost	Bill Factor	Bill Amount	Holdback 15%	Invoice Amount	Cash Inflow
Sep-92	0	$20,000	$2,879.80	$17,120	1.04	$17,805	$2,670.75	$15,134.26	$0.00
Oct-92	1	$359,987	$2,879.80	$357,107	1.04	$371,391	$55,708.65	$315,682.76	$15,134
Nov-92	2	$123,892	$2,879.80	$121,012	1.00	$121,012	$18,151.80	$102,860.37	$315,683
Dec-92	3	$483,443	$2,879.80	$480,563	1.00	$480,563	$72,084.45	$408,478.72	$102,860
Jan-93	4	$606,899	$2,879.80	$604,019	1.00	$604,019	$90,602.88	$513,416.32	$408,479
Feb-93	5	$1,090,342	$2,879.80	$1,087,462	1.00	$1,087,462	$163,119.33	$924,342.87	$513,416
Mar-93	6	$1,697,241	$2,879.80	$1,694,361	1.00	$1,694,361	$254,154.18	$1,440,207.02	$924,343
Apr-93	7	$2,787,583	$2,879.80	$2,784,703	1.00	$2,784,703	$417,705.48	$2,366,997.72	$1,440,208
May-93	8	$1,090,387	$2,879.80	$1,087,507	1.00	$1,087,507	$163,126.08	$924,381.12	$2,366,998
Jun-93	9	$500,654	$2,879.80	$497,774	1.00	$497,774	$74,666.13	$423,108.07	$924,381
Jul-93	10	$140,667	$2,879.80	$137,787	1.00	$137,787	$20,668.08	$117,119.12	$423,108
Aug-93	11	$0		$0	1.00	$0.00	$0.00	$0.00	$117119
Sep-93	11.5	$0		$0	1.00	$0.00	$0.00	$0.00	$1,332,658
Totals		$8,901,095					$1,332,658		$8,884,377

Table 3-6: Present value of cash inflow for project

Date	Per. #	Invoice Amount	PV factor	PVinflow
Sep-92	0	$0.00	1.000	$0.00
Oct-92	1	$15,134.26	0.976	$14,765.13
Nov-92	2	$315,682.76	0.952	$300,471.40
Dec-92	3	$102,859.52	0.929	$95,515.29
Jan-93	4	$408,477.87	0.906	$370,060.79
Feb-93	5	$513,415.47	0.884	$453,784.46
Mar-93	6	$924,342.02	0.862	$797,057.23
Apr-93	7	$1,440,206.17	0.841	$1,211,595.38
May-93	8	$2,366,996.87	0.821	$1,942,704.56
Jun-93	9	$924,380.27	0.801	$740,177.50
Jul-93	10	$423,107.22	0.781	$330,530.68
Aug-93	11	$117,118.27	0.762	$89,261.08
Sep-93	11.5	$1,332,656.59	0.753	$1,003,214.50
			PVin =	$7,349,138.01

The recommended bid markup is calculated using equation 3.1 as follows:

$$\text{Recommended Markup} = \frac{PVout}{PVin} - 1 = \frac{\$7,618,918}{\$7,349,138} - 1$$

$$\text{Recommended Markup} = 0.037 \text{ or } 3.7\%$$

The recommended markup of 3.7% is then applied to the direct cost of the project ($8,901,095). Other project indirect costs such as bond premiums, insurance premiums, or contingencies are then added to determine the project bid price.

The cumulative cash flow diagram representing the project cash flows after the markup is applied is shown in Figure 3-7.

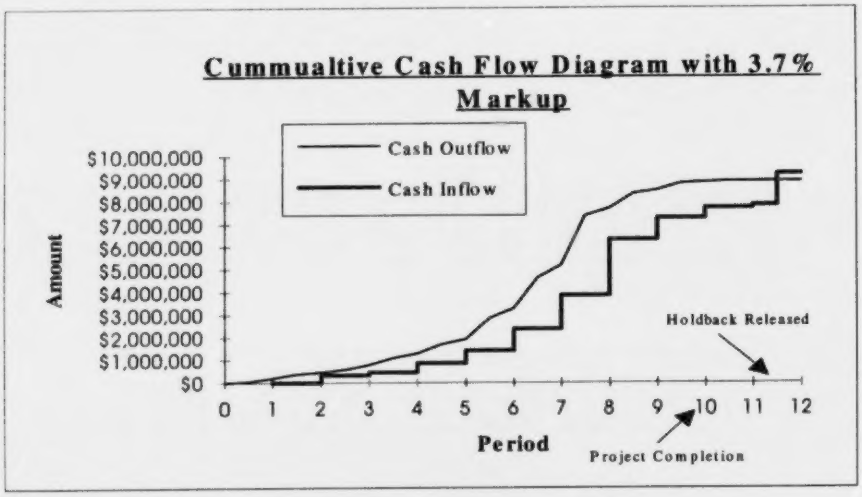


Figure 3-7: Cash flow diagram of example after markup is applied

The cumulative cash flow diagram illustrates the financing requirements of the example project and shows that cash excess or profit occurs at the end of the project. The cash excess at the end of the project is found to be 3.7% of the project total cost and confirms the recommended markup determined by the cash flow model.

3.6 Sensitivity Analysis of Cash Flow Model

The parameters used by the cash analysis model are varied to test the model's sensitivity to input changes. The variables tested include required rate of return, project payment policy, and holdback amounts. An analysis is also provided for the project's internal parameters such as the different cost categories. The sensitivity analysis is conducted using the Monte Carlo technique. Numerous projects are generated for which the markup is determined. The projects are generated from a variable triangular distribution where the shape of the distribution changes for every project. The lower point of the triangular distribution is set to 0 and the upper point is equal to the duration (months) of the project. The duration is generated randomly from a uniform distribution over the interval [3,25]. The mode of the triangular distribution is generated randomly from a uniform distribution over the interval [30% of duration, 70% of duration]. A sample triangular distribution is shown in Figure 3-8 with a duration of 8 periods and the possible range of 30 -70% for the mode is shown along with the actual randomly generated mode of the distribution.

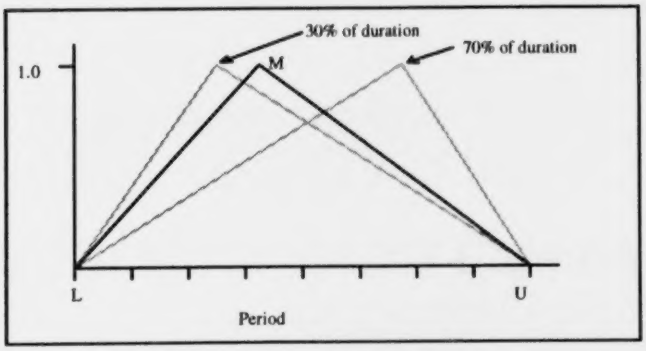


Figure 3-8: Sample triangular distribution for a project cost curve

The project cost curve is then derived from the CDF of the triangular distribution. The CDF is mathematically determined using the equations 3.9 and 3.10 which calculate the cumulative cost multipliers (CCM) for the project period (y).

$$CCM(y) = \frac{y^2}{M * U} \qquad if\, y < M \tag{3.9}$$

$$CCM(y) = \frac{(U-y)^2}{(U-M) * U} \qquad if\, y >= M \tag{3.10}$$

where:

U = upper limit of triangular distribution.
M = mode of triangular distribution.
y = period number

The project cost is generated randomly from a uniform distribution over the interval [0.5million, 20million] and the cumulative cost per period is derived by multiplying the total project cost by the cumulative cost multipliers from equations 3.9 and 3.10. An initial project cost is calculated using an amount fixed at 0.15% of the total project cost. The amount assessed to each cost category is also randomly generated from uniform distributions over intervals of [10%,50%] of the cost per period (or remaining cost). The sensitivity analysis consists of 40 runs for each increment of the tested parameter. The procedure of the Monte Carlo study is summarized as follows:

1. Select test variable
2. Select amount fixed amount for test variable.
3. Repeat for 40 runs:
    - 3a. Generate project.
    - 3b. Apply cash flow analysis model to determine markup.
4. Calculate statistics

For example, to test the sensitivity of holdback amount, 40 runs are performed using a holdback of 10% then 40 runs are performed using a holdback of 20% and the simulations are compared. The average markup is calculated for all 40 along with the corresponding standard deviation and 95% confidence interval. The Monte Carlo method has been programmed using the Basic Professional Development System and the algorithm for the code is provided in Appendix A.

3.6.1 Sensitivity to RRR

The sensitivity of the model to required rate of return (RRR) is conducted by varying the RRR from 0% to 10% per month. The project markup is evaluated by the cash flow analysis model for different rates of return; other parameters are held constant (holdback amount at 15%, payment policy at 20 workdays and the holdback release at 45 days). The results of the sensitivity test are plotted in Figure 3-9. The results show an increasing linear pattern to describe the relationship between RRR and average recommended project markup. The linear relationship shows that the recommended project markup is sensitive to modifications in the RRR from the slop of approximately 1 to 1.8, where any change in

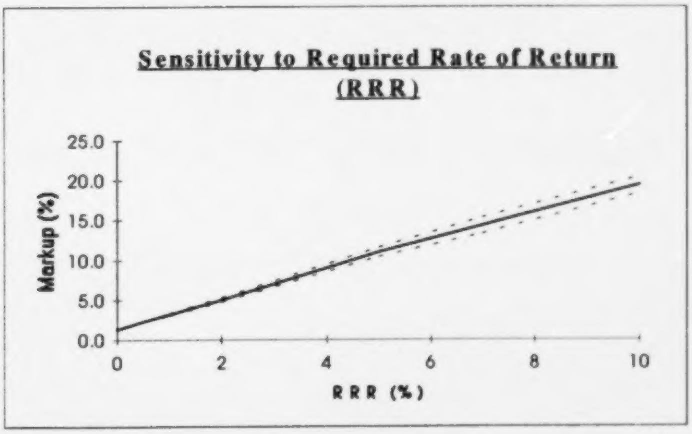


Figure 3-9: Sensitivity of project markup to RRR

RRR is magnified by a 1.8 times the markup value (slope of the curve). The relationship is considered highly significant since a markup adjustment of 0.1% can be the difference in receiving a contract award. The sensitivity analysis to RRR shows that a company should consider the determination of RRR with caution and include all variables since it has a significant role in the calculation of project markup.

The magnitude of the 95% confidence interval increases as the RRR increases indicating that the accuracy of the markup is proportional to its magnitude. To check the normality and support the accuracy of the confidence interval the quantile-quantile (q-q) plot of the markup and the normal distribution is developed for each simulation. The q-q plot for RRR 1% and RRR 0.5% is shown in Figures 3-10 and 3-11. The plot in Figure 3-10 shows a near linear relationship. However, the curve of Figure 3-11 deviates slightly from a linear relationship and thus the accuracy of the confidence interval is not proved. The q-q plot at RRR 0% (provided in Appendix B) deviates from a linear curve and hence the confidence interval can not be considered as accurate. The charts summarizing the 40 runs of each RRR increment along with remaining q-q plots and tables of values for the sensitivity analysis are provided in Appendix B.

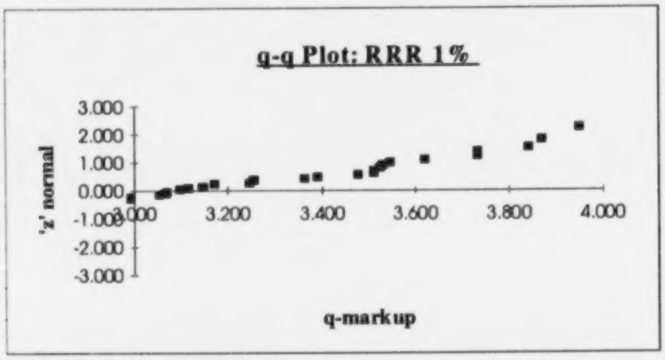


Figure 3-10: Quantile-Quantile plot for RRR = 1%

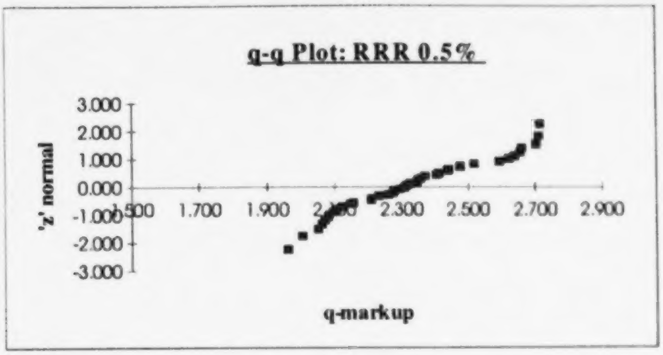


Figure 3-11: Quantile-Quantile plot for RRR = 0.5%

3.6.2 Sensitivity to Holdback

The sensitivity of the model to the project holdback amount is conducted by varying the project holdback amount from 0% to 30% of total project billings. The project markup is determined by the cash flow analysis model for different holdback amounts; other parameters remain constant (RRR at 2.5%, project payment policy at 20 work days, and the holdback release at 45 days following the completion of the project). The results of the sensitivity test are plotted in Figure 3-12 with the relationship between the variables described as an increasing linear pattern. The linear relationship shows that the project markup is sensitive to the holdback amount by the slope of approximately 6.6 to 1 where a change of the 10% holdback results in a 1.5% change in markup.

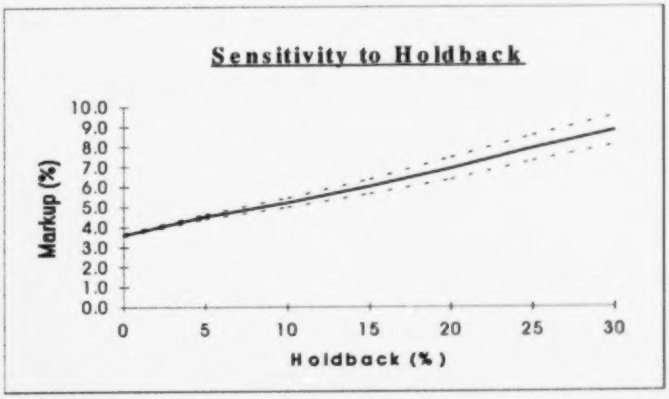


Figure 3-12: Sensitivity of project markup to holdback amount

Similar to the RRR analysis the magnitude of the 95% confidence interval increases as the holdback amount increases indicating that the accuracy of the markup is directly proportional to its magnitude. To confirm normality and confirm the accuracy of the confidence interval, the q-q plot for each holdback amount is constructed with all plots similar to Figure 3-13.

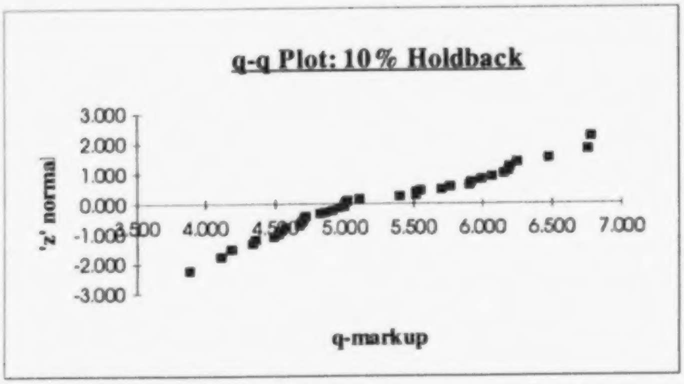


Figure 3-13: Quantile-Quantile plot for holdback amount 10%

The q-q plot shows a linear relationship and hence proves the accuracy of the stated confidence intervals. The sensitivity analysis demonstrates that the cost of a project can be reduced by 1.5% by reducing the holdback amount from 15% to 5% which is a considerable saving to the owner and to the contractor who takes advantage of such adjustments in a contract. Typically the amount of holdback incorporated into a contract is determined by the liability assumed by the owner. The owner's liability results from legislation which states that an owner is liable for a certain amount (15% in Alberta) of the contract price to contractors, subcontractors, and suppliers until a specified time following the completion of the contract. Therefore, most owners do not consider the 0.5% to 1% possible savings on a project an adequate trade off for the possible liability incurred (15% of contract price). However on *mega* projects, an owner might try to obtain exemptions from such legislation since a 0.1% saving amounts to a significant dollar value. The charts summarizing the 40 runs for each simulation along with q-q plots and tables for the sensitivity analysis are provided in Appendix C.

3.6.3 Sensitivity to Payment Policy

The sensitivity of the model to the payment policy is conducted by varying the payment policy from 5 to 40 working days and the recommended project markup is determined by the cash flow analysis model. The time of the payment policy includes both the consultants approval time and the owners payment time requirement. Other variables are held constant (RRR at 2.5%, holdback amount at 15%, and the holdback release at 45 days following contract performance). The result of the test is plotted in Figure 3-14 with the relationship between the payment policy and markup described by an increasing linear pattern. The linear relationship shows that the project markup is sensitive to the contract payment policy from the slope of approximately 10 to 1 where a 10 day change in the policy results in a 1% change in the project markup. The analysis shows that an owner can reduce the cost of his project by reducing the amount of time the contractor awaits payment.

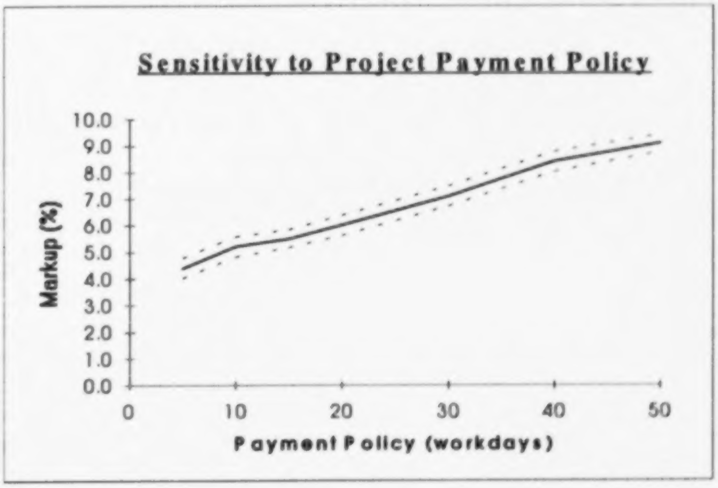


Figure 3-14: Sensitivity of project markup to payment policy

Contrary to the RRR and holdback analysis the magnitude of the 95% confidence interval remains constant throughout the analysis indicating that the accuracy of the markup is not proportional to its magnitude. To confirm normality and the accuracy of the confidence interval, the q-q plot for each holdback amount is constructed with all plots similar to Figure 3-15.

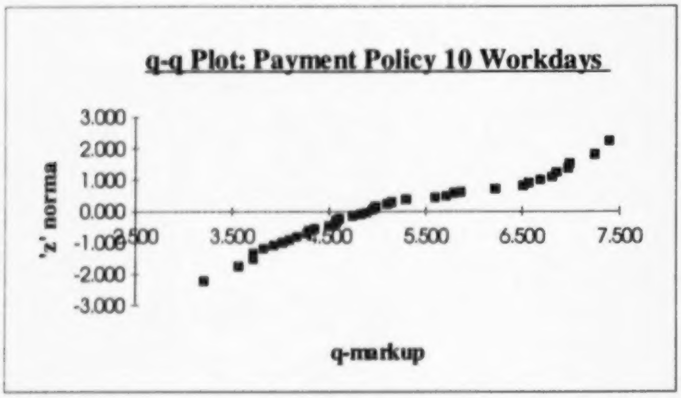


Figure 3-15: Quantile-Quantile plot for payment policy =10 workdays

The q-q plot shows a linear relationship and hence proves the accuracy of the stated confidence intervals. The payment policy factor is a controllable factor that the owner prescribes in the contract and thus can be easily modified to obtain a cost savings without incurring any liability. For example, in Alberta the typical government payment period is 20 working days, however this can be reduced to 10 days without the government assuming any liability. The resulting savings would be nearly 1% of the contract price. The sensitivity analysis can also be used to demonstrate the effects of delaying the payment of invoices due to any discrepancies. Typically, if a particular item is in dispute on an invoice the consultant will not approve the entire invoice and this results in a delayed payment. The effect of the delayed payment can be quantified from the sensitivity analysis chart by showing the variation in markup between expected payment time and actual payment time which is helpful in contract dispute resolution. The payment policy time of zero was not considered since it is not practical to have no payment lag time for any project invoice. The charts summarizing the 40 runs of each simulation with other q-q plots and tables for the sensitivity analysis are shown in Appendix D.

3.6.4 Sensitivity to Labour Cost Category

The sensitivity of the model to the labour cost category is conducted by varying the amount of the labor component from 10% to 60% of the total project cost and the recommended project markup determined from the cash flow analysis model. The payroll burden is modified accordingly since it is input as a percentage of the labour amount. The external parameters are held constant for each simulation (payment policy at 20 working days, the required rate of return at 2.5% per month, the holdback at 15%, and the hold back release at 45 days). The results of the sensitivity test are plotted in Figure 3-16 with a flat curve describing the relationship between labour and recommended project markup.

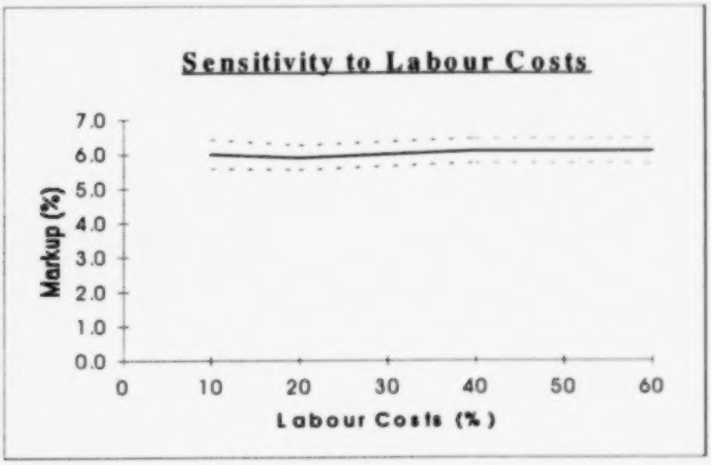


Figure 3-16: Sensitivity analysis of project markup to labour costs

The variation in the average markup over each labour increment is less than the 95% confidence interval which is relatively constant for all simulations. To confirm normality and the accuracy of the 95% confidence interval, the q-q plot for each labour increment is completed and is shown in Appendix E. The q-q plots illustrate a near linear relationship for the 20% and 40% labour amounts but deviating from a linear curve for the 10% and 60% increments therefore the accuracy of the 95% confidence interval at the outer points is not proven. The sensitivity of the markup to the labor cost category is minimal and the Monte Carlo study does not show a changing relationship between the variables. A single project is analyzed where the labour amount is varied for each run and the remaining cost categories are determined using a fixed percentage of the remaining period costs. An example of the single project analysis is shown in Figure 3-17 where an increasing linear curve describes the relationship between the project markup and labour amount.

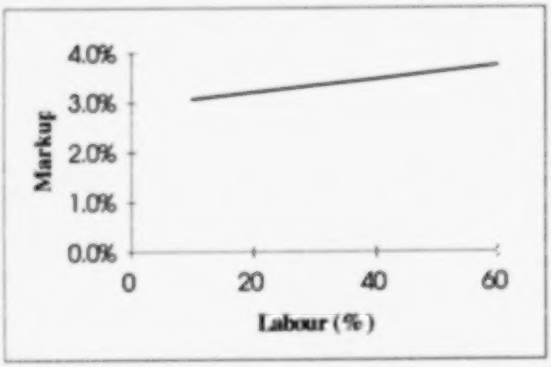


Figure 3-17: Single project analysis of labour costs

The linear relationship shows that a recommended project markup is minimally sensitive to modifications of the labour cost category by a slope of 80 to 1, where an 80% change in allocation of labour results in a 1% change in the project markup. This relationship is considered minimally significant unless a contractor is considering subcontracting the majority of a project, then a possible markup reduction of 0.1 to 0.3% might be attainable. The sensitivity of the markup to the labour cost is project specific as demonstrated in the Monte Carlo study of 40 simulated runs. The single project analysis is highly dependent on the other internal cost parameters and the distribution among them. The variables input into the cash flow analysis model which are provided along with markup calculations in Appendix E.

3.6.5 Sensitivity to Material Cost Category

The sensitivity of the model to the material cost category is conducted by varying the amount of the material component from 10% to 60% of the total project cost and the recommended project markup determined from the cash flow analysis model. The external parameters are held constant (RRR at 2.5%, the payment policy at 20 working days, the holdback amount at 15% and the holdback release at 45 days). The results of the sensitivity test are shown in Figure 3-18 with a decreasing linear pattern describing the relationship between material and recommended project markup, and a constant 95% confidence interval.

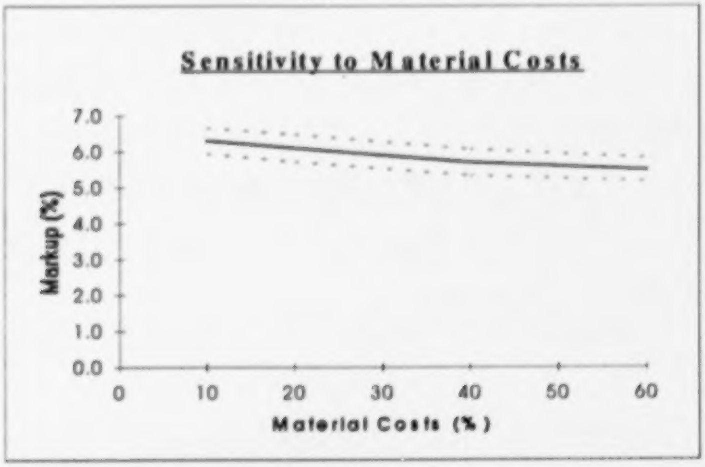


Figure 3-18: Sensitivity analysis of project markup to material costs

The linear relationship shows that a recommended project markup is minimally sensitive to modifications of the material cost category by a negative slope of 50 to 1, where a 50% change in allocation of material results in a negative 1% change in the project markup. To confirm normality and the accuracy of the 95% confidence interval, the q-q plots were completed with all plots similar to Figure 3-19.

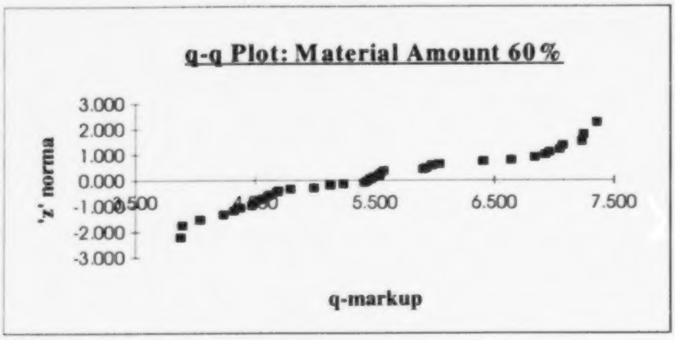


Figure 3-19: Quantile-Quantile plot of 60% material amount

The q-q plot is near linear and therefore the accuracy of the 95% confidence interval is confirmed. The relationship of material amount and markup decreases linearly since the material cost has the least time lag between cash inflow and outflow, hence by allocating more funds to a smaller lag time the required project markup is reduced. The relationship is considered minimally significant but can be used by contractors to slightly adjust their bid markups (by 0.1%) on projects that become labour intensive as opposed to material intensive. The Monte Carlo study results are applicable to the equipment cost category since it also has the same type of cash outflow/inflow lag time. Similar to the labor category the analysis of material costs is highly dependent on the other variables input into the cash flow analysis model. The charts summarizing the 40 run simulation, other q-q plots and tables for the sensitivity analysis are provided in Appendix F.

3.6.6 Sensitivity to Operating Costs Category

The sensitivity of the model to the operating cost category is conducted by varying the amount of the operating component from 10% to 60% of the total project cost and determining the recommended project markup from the cash flow analysis model. The external parameters are again held constant for each simulation (RRR at 2.5%, payment policy at 20 work days, holdback at 15%, and holdback release at 45 days). The results of the sensitivity test are shown in Figure 3-20 with a flat curve describing the relationship between material and recommended project markup.

Since the curve is flat it indicates that the project markup is not sensitive to the category of operating costs with any variation in markup within the constant 95% confidence interval. To confirm normality the q-q plots were completed with each plot illustrating a near linear relationship therefore proving accuracy of the 95% confidence interval. The sensitivity of markup to operating costs is tested using a single project as previously performed for the labour category. The single project analysis with fixed distributions to all cost categories results in an increasing linear relationship between markup and operating cost as illustrated by the example shown in Figure 3-21.

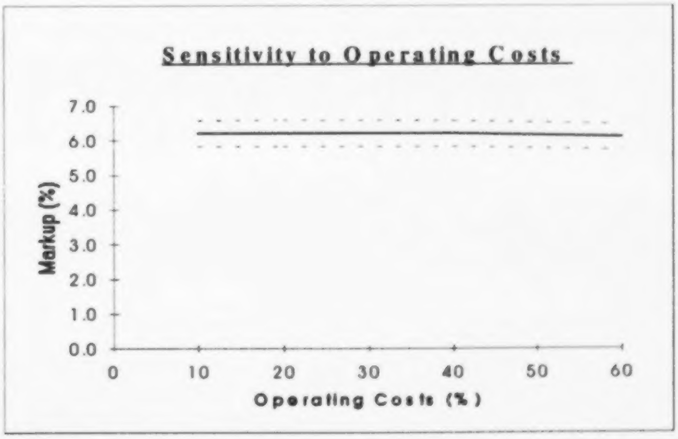


Figure 3-20: Sensitivity analysis of markup to operating costs

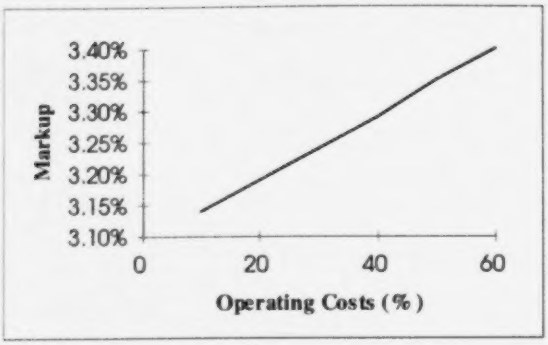


Figure 3-21: Single project analysis of operating costs

The linear relationship shows that a recommended project markup is minimally sensitive to modifications of the operating costs category by the slope of 200 to 1 where a 200% change in allocation of operating costs results in a 1% change in the project markup. The relationship is not considered significant but can be used by contractors to slightly adjust their bid markups (by 0.05%) on projects when the cost of operations can be deferred to the end of the period and treated similar to the materials or equipment categories. Similar to the previous analysis, operating cost is highly dependent on the other variables input into the cash flow analysis model. Charts summarizing the Monte Carlo study, q-q plots and tables of the sensitivity analysis are provided in Appendix G.

3.7 Conclusions

The cash flow analysis model provides a lower recommended markup than the other models using the present value analysis technique. In the example application, a recommended markup of 3.7% resulted while the Farid and Boyer FaRM model returns a markup of 4.3% for the same project. The calculations of the FaRM are provided in Appendix H. The difference of 0.6% is currently a significant amount in the construction industry where projects are won or lost by less than a 0.1% markup. The competitiveness of the project price has increased in the negotiated contract environment since a client is likely to believe that the markup applied is fair. The lower markup results from the breakdown of the project into cost categories where each category has varied cash inflow and outflow times.

The Monte Carlo study performed on the cash flow model illustrates sensitivity to the external factors of RRR, holdback amount, and payment policy, but minimal sensitivity to internal cost variables such as the labor, material, and operating cost categories.

The application of the model is not limited to the determination of a project bid price but can also be used in claim disputes and other contract resolutions as a method of quantifying changes and impact costs of a project. The sensitivity analysis shows that an owner can reduce the cost of a project by decreasing the payment policy of the project contract or the holdback amount. Similarly, a contractor can use the sensitivity analysis to apply markups to issued change orders, and to use contract changes to a competitive advantage.

The cash flow analysis model assumes that the required rate of return is known by the user and the rate allows appropriate compensation for risk and financing. The cash flow model has been automated using the Basic Professional Development System and the algorithm for the code was provided in Appendix A.

Chapter 4: Utility Theory Model

4.1 Introduction

Utility theory is used to develop a functional relationship between a single criterion and its utility value. The functional relationship may be exponential or linear. A linear relationship is shown in Figure 4-1, where a criterion input selection of *medium* results in a utility value of 0.38.

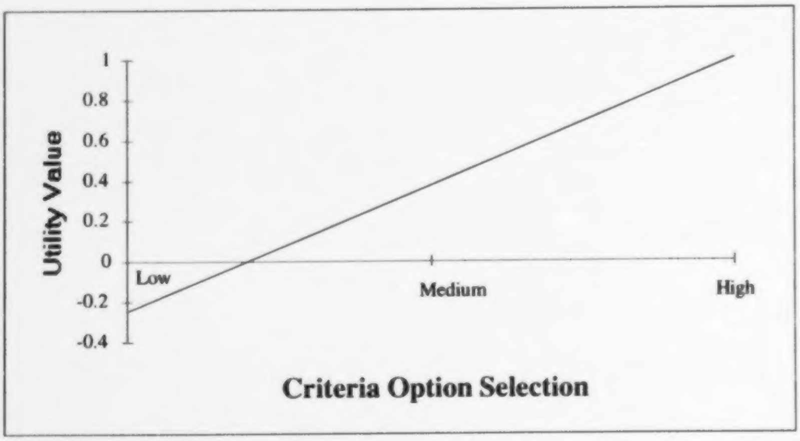


Figure 4-1: Sample of a linear utility function

In the utility theory model, 21 bidding criteria have been identified. The model thus has 21 utility functions. Utility values are combined with a multi-criteria, multi-alternative decision technique similar to one developed by Lifson and Shaifer (1982).

To determine the bid markup of a new construction project a utility theory model is developed with the procedural steps outlined in the flowchart shown in Figure 4-2.

The utility theory model discussed in the chapter has been automated using the Basic Professional Development System (the algorithm is provided in Appendix A).

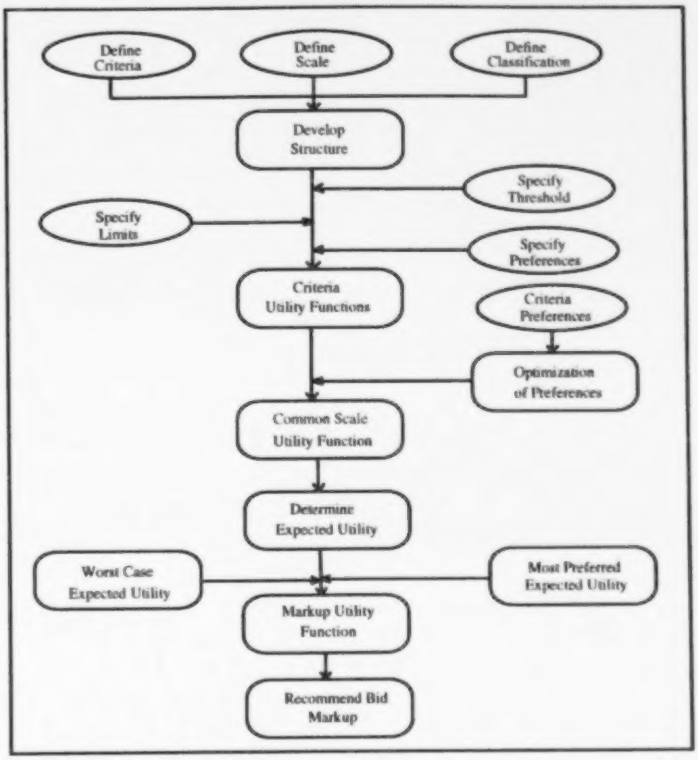

Define Criteria
Define Scale
Define Classification
Develop Structure
Specify Threshold
Specify Limits
Specify Preferences
Criteria Utility Functions
Criteria Preferences
Optimization of Preferences
Common Scale Utility Function
Determine Expected Utility
Worst Case Expected Utility
Most Preferred Expected Utility
Markup Utility Function
Recommend Bid Markup

Figure 4-2: Flowchart of utility theory model

4.2 Identification and Structure of Bidding Criteria

The application of the utility model requires the criteria used in the bidding decision be defined and represented by utility functions. To identify the various bidding criteria, a survey performed by Ahmad and Minkarah (1988) is taken as the basis. The bidding criteria and definitions of criteria are shown in Table 4-1. Definitions and scale for each criteria are also identified. The scale for each criteria is either a numerical value or a subjective input.

Table 4-1: Definition and scale of bidding criteria

Hierarchy Block	Criterion Name	Definition	Criterion Scale
1.1.1	Location	Is project within company boundaries.	Yes = 100 No = 0
1.1.2	Labour Reliability	Is local labour well trained, skilled.	Good = 100 Fair = 50 Poor = 0
1.1.3	Labour Availability	Is local labour available or difficult to obtain.	Easy = 100 Difficult = 50 Impossible = 0
1.2.1	Market Conditions	Other projects currently out for tender. (Relative to number of competitors bidding).	Many = 100 Average = 50 Few = 0
1.2.2	Competition	Expected number of serious competitors bidding on the project.	Number (#)
1.2.3	Future Projects	Forecast of upcoming projects.	Many = 100 Average = 50 Few = 0
1.3.1	Historic Profit	Amount of profit obtained on past projects of similar nature	Percent (%)
1.3.2	Historic Failures	Past known failures for this project type/owner etc.	Many = 100 Few = 50 None = 0
2.1	Current Workload	Volume of all current projects relative to capacity of firm.	High = 100 Medium = 50 Low = 0
2.2	Required Rate of Return	Required rate of return on investment required by firm.	Percent (%)
2.3	Market Share	Ratio of Current Market Share by expected share.	Percent (%)
2.4	Overhead Recovery	Indirect overhead recovered this annum.(relative to forecasted).	Percent (%)
2.5	Home Office Workload	Amount of project to be completed by home office forces.	Percent (%)
3.1	Project Type	Project type. Is type within the scope of the firm.	Yes = 100 No = 0
3.2	Project Size	Estimated project dollar volume	Dollars ($)
3.3	Owner	Relationship between owner and firm.	Good = 100 Average = 50 Poor = 0
3.4	Other Risk	Other risk factors of project to be included and their effect on the project outcome..	High = 100 Medium = 50 Low = 0
3.5	Project Complexity	Is complexity of project beyond capability of firm.	Yes = 100 No = 0
3.6	Project Duration	Expected duration of project.	Months
3.7	Cash Flow Req'mnts	Average project cash flow requirements for each period.	Dollars ($)
3.8	Estimate Uncertainty	Uncertainty in the cost estimate. May be due to insufficient information etc.	High = 100 Medium = 50 Low = 0

The bidding criteria considered by ICBS is divided into groups and organized in a hierarchical structure format. The hierarchical structure is shown in Figure 4-3. The classifications include, environment factors, company factors, and project factors. Environmental factors are further separated into geographical, economic and historic groups.

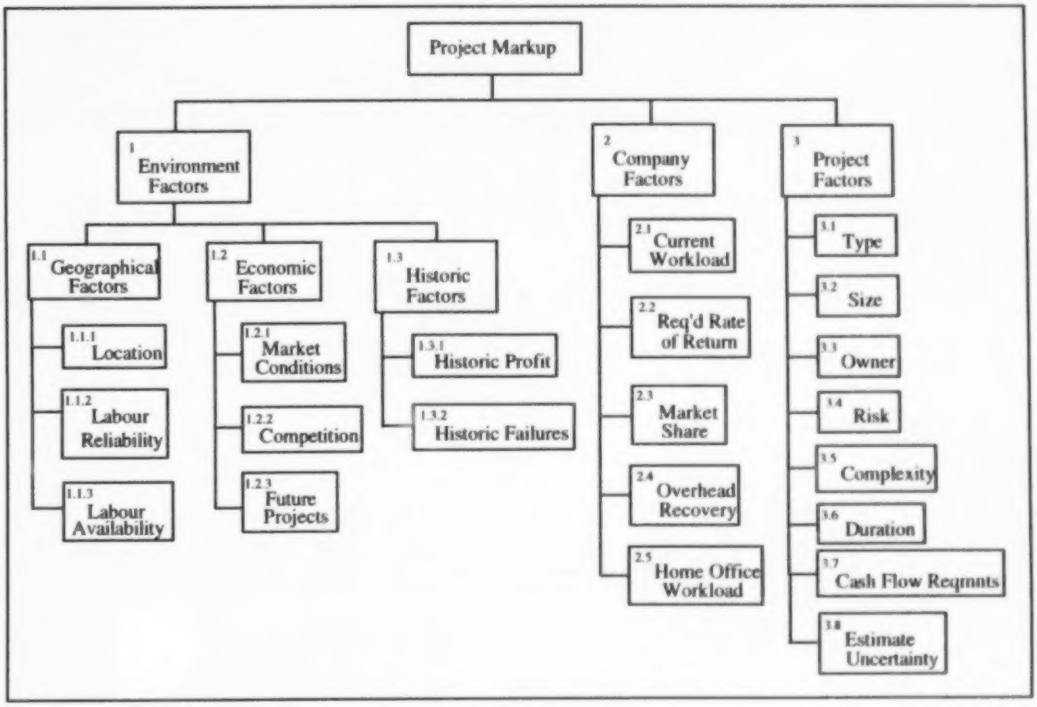

Project Markup
1 Environment Factors
1.1 Geographical Factors
1.1.1 Location
1.1.2 Labour Reliability
1.1.3 Labour Availability
1.2 Economic Factors
1.2.1 Market Conditions
1.2.2 Competition
1.2.3 Future Projects
1.3 Historic Factors
1.3.1 Historic Profit
1.3.2 Historic Failures
2 Company Factors
2.1 Current Workload
2.2 Req'd Rate of Return
2.3 Market Share
2.4 Overhead Recovery
2.5 Home Office Workload
3 Project Factors
3.1 Type
3.2 Size
3.3 Owner
3.4 Risk
3.5 Complexity
3.6 Duration
3.7 Cash Flow Reqmnts
3.8 Estimate Uncertainty

Figure 4-3: Hierarchical structure of bidding criteria

The classification of the bidding criteria provides an understandable representation of the factors involved in bidding. Classifications and criteria are numbered according to the hierarchical numbering system.

4.3 Development of Utility Functions for Defined Criteria

Each bidding criteria is represented by a utility function so that the selected option of each criteria can be transformed to a common scale for comparison with other bidding criteria options. To develop a utility function for a particular criteria the utility function should represent the user's preferences over a range of options. The utility functions for all criteria should represent preferences or trade-offs between criteria and should be measured on a scale so that expected utilities of individual criteria can be combined to form a *single expected utility*. The methodology used to develop the utility function of each criteria can be summarized as follows:

1. Specify the range of interest for each criteria, upper and lower limits (y_U,y_L).
2. Identify the neutral point of contribution for each criteria, threshold (y_T) and the most preferred point (y_M).
3. Define the cardinal utility scale by anchoring relative points.
4. Develop the utility functions using either a straight-line or exponential function and solve for the constants of each equation.

The range of interest identifies the upper and lower limits (y_U,y_L) for the options of each criteria and become the boundaries for numeric inputs. For criteria that rely on subjective input default values which bound the fuzzy scale are used. These are shown in Table 4-1. For example, the criteria *Project Size*, the maximum size specified by the policy of the firm may be \$30million and the smallest size \$0.1million, meaning that the firm will not bid any projects outside these limits.

The threshold point (y_T) of each criteria represents the point of neutral desirability. The most preferred point (y_M) represents the best possible option for the particular criteria. Both the threshold and most preferred points are specified by an estimator.

The scale for each utility function is derived by fixing the utility values with specific options for each criteria. These options are referred to as relative points and a minimum of two are required depending on the method used for developing utility values. For two relative points, the threshold point (y_T) and the most preferred amount (y_M) are used. The utility of the threshold point will be set to zero and the utility of the most preferred point of each criteria is set to one.

$$u(y_T)_j = 0 \quad \text{and} \quad u(y_M)_j = 1$$

If a third relative point is required, an estimator will subjectively determine the utility of another criteria option selection (possibly the upper or lower bounds can be used).

The utility functions are created by using either a straight line relationship or an exponential relationship. Each utility function can be developed with the appropriate equation:

Straight-line equation: $$u_j(y_j) = A_j y_j + B_j \tag{4.1}$$

Exponential equation: $$u_j(y_j) = A_j e^{B_j y_j} + C_j \tag{4.2}$$

where:

$u_j(y_j)$ = utility of criteria j

A_j, B_j, C_j = constants of the function for criteria j

For the application of utility theory in ICBS, the utility functions for each bidding criteria will be developed using the straight-line method as previously shown in Figure 4-1.

The straight-line method is a good approximation for ICBS since the model is at a conceptual stage of development and the sensitivity of either method has not been explored for this particular application of utility theory.

The constants of the straight line equation are solved using two relative points of the criteria for which the utility is known from subjective judgment or company policy.

These points are the most preferred option and the threshold option. The utility of each is described above.

4.4 Scaling (Weighting) Factors of Bidding Criteria

The scaling (or weighting) factors assigned to each criteria distinguish the preferences or trade-offs between criteria that are in the same classification and on the same level of the hierarchical structure. The scaling factors are used to combine all criteria under each classification within the structure. The scaling factors are distributed so that the sum of each classification and sub-classifictaion level equals 100. The preferences of the bidding criteria within each classification (or subclass) are likely to remain constant however the preferences of the classifications are likely to change frequently, the preference summation requirement of 100 allows for the adoption of an adjustment system as discussed later.

The scaling factors (W_j) are assigned to all bidding criteria based on classification in the hierarchical structure as discussed above. For all the criteria in a particular classification or sub-classification an estimator will dictate the preferences or trade-offs between criteria. Preferences for sub-classifications and classifications are also required for a comparison on the same level within the structure. The input preferences are then manipulated to derive the optimum scaling factors for each criteria, sub-classification and classification.

The preferences of the bidding criteria are set up in a square matrix as in Figure 4-4 which shows all criteria of the sub-classification *Economic Factors* on both the horizontal and vertical axis of the matrix. Each row of the matrix contains the preference of the row criteria compared to the column criteria based on a scale of 0 to 5. The preference scale is the set of numerals {0, 0.1, 0.5, 1.0, 1.5, 2, 3, 4, 5}. For the matrix shown, the criteria *market conditions* is considered 2.0 times (twice) as important than the criteria *competition,* and 5.0 times as important as the criteria *future projects.* Similarly, the criteria *competition* is 4.0 times as important than the criteria *future projects.* If two criteria are of equal importance then the preference value is 1.0 (equal). No preferences are required on or below the diagonal of the matrix since all values below the matrix are the reciprocal of the upper triangle. All preference values along the diagonal are 1.0 since a criteria cannot have a different importance than itself.

Bidding Criteria	Market Cond.	Competition	Future Proj.
Market Conditions	1.0	2.0	5.0
Competition	----	1.0	4.0
Future Projects	----	----	1.0

Figure 4-4: Matrix of preferences for bidding criteria

The matrix of preferences is manipulated using a method described by Saaty (1978) which determines the eigenvector corresponding to the maximum eigenvalue of a matrix. This method produces the optimum scaling factor for each of the bidding criteria that maximizes the combination of all criteria in the classification. The eigenvector for the matrix in Figure 4-4 is (0.57, 0.33, 0.10) using the maximum eigenvalue of 3.02. The maximum eigenvector of scaling factors is then distributed to each criteria in the matrix as follows; scaling factor of *market conditions* is 57, scaling factor of *competition* is 33 and the scaling factor of *future projects* is 10. The procedure is repeated for the elements of all classifications and sub-classifications for the hierarchical structure of bidding criteria.

The scaling factors of the bidding criteria (W_j) are adjusted as per the classification or sub-classification in which they are located within the hierarchical structure. Also, each sub-classification is adjusted as per the classification under which it is located. The scaling factors of the bidding criteria are adjusted using the scaling factors of the classification and sub-classification by the equation:

$$S_j = \textit{Classification scaling factor/100} * W_j \qquad (4.3)$$

or

$$S_j = Classification\ scaling\ factor/100 * Sub\text{-}Class\ Scale\ factor/100 * W_j \quad (4.4)$$

Equation 4.3 is similarly applied to all sub-classifications of the bidding structure. The sum of the adjusted scaling factors of the bidding criteria should equal 100, this calculation is performed as a check to ensure no errors have been made in assigning or adjusting scaling factors.

4.5 Transformation of Utility Functions

The utility values of each criteria are combined to form an expected utility for a project scenario. To combine the bidding criterion, Lifson and Shaifer (1982) recommend the utility function for each criteria $u_j(y_j)$ be transformed to a common scale utility function $U_j(y_j)$ using the scaling factor and the transformation equation:

$$U_j = a_j u_j + b_j \quad (4.5)$$

The utilities of the threshold point $(y_T)_j$ and the most preferred point $(y_M)_j$ are used to determine the constants a_j and b_j the scale transformation equation by setting;

$$U_j(y_T) = 0 \quad \text{and} \quad U_j(y_M) = S_j$$

The transformation equation reduces to:

$$U_j(y_j) = S_j u_j(y_j) \quad (4.6)$$

The equation 4.6 is used to determine the utility function of each criteria on a common utility scale.

4.6 The Expected Utility Value

The *expected utility value* (also referred to as *total relative score*) is determined using the transformed utility functions of each bidding criteria. The options selected for each bidding criteria are manipulated to form transformed utility values. The summation of the transformed utilities for all the bidding criteria determines the expected utility value (Eu) for the project scenario.

4.7 The Markup Utility Function

The markup utility function transforms the expected utility value into a bid markup (percent) recommendation. The markup utility function is derived from a straight-line relationship similar to previously developed bidding criteria utility functions. The function is divided into two straight-line equations but only one equation will apply to a single project scenario. The procedure for application is as follows:

> *If the expected utility value (Eu) for a project is greater than or equal to the expected utility of the threshold points (Eu_t) then equation 4.7 applies as the markup function:*
>
> $$M(Eu) = EuC + D \tag{4.7}$$
>
> *Else if Eu is less than Eu_t then equation 4.8 applies as the markup function:*
>
> $$M(Eu) = EuG + H \tag{4.8}$$
>
> where: $M(Eu)$ = percent markup for the expected utility value
> C, D, G, H are constants

To define the markup utility function the most common largest and smallest acceptable bid markups used by the company are required. The expected utility is determined for the following bidding criteria selections:

1. Most preferred options (Eu_p)
2. Worst case options (Eu_w)

The expected utility of the threshold selections (Eu_t) is zero since the utility value of the threshold points are fixed to 0. The markup of the expected utility values Eu_p, Eu_t, and Eu_w is assigned to the company markups specified and used to solve for the unknowns of the markup utility function equations.

To solve for constants *C & D* of equation 4.7:

1. $M(Eu_t)$ = most common markup of company
2. $M(Eu_p)$ = smallest markup of company

To solve for constants *G & H* of equation 4.8:

1. $M(Eu_t)$ = most common markup of company
2. $M(Eu_w)$ = largest markup of company

The markup function is composed of two separate functions as the slope of the utility function above the most common markup is different from the slope of the function below the most common markup as shown in Figure 4-5.

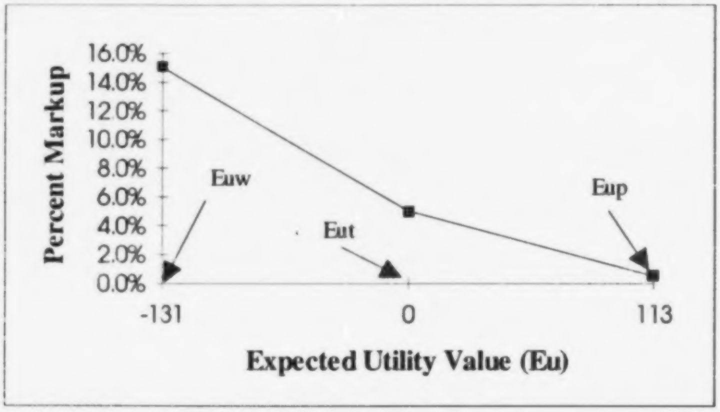


Figure 4-5: Markup utility function

4.8 Example Application

The following is an example application of the utility theory model applied to the bid markup decision of a specific project. The user specified a range for each of the bidding criteria (limits y_U and y_L) as well as the threshold (y_T) and most preferred (y_M) points which are presented in Table 4-2. The constants A and B for the straight line utility functions are solved using; $y_T = 0$ and $y_M = 1$, the constants are also shown in this table.

The preferences of the bidding criteria are solicited on the 0 to 5 scale (0, 0.1, 0.5, 1.0, 1.5, 2, 3,4, 5) with responses placed in a square matrix for each class or sub-class.

Table 4-2: Range, threshold, most preferred point and constants for criteria

Block ID	y_U	y_L	y_T	y_M	A	B
1.1.1	100	0	50	100	0.02	-1.0
1.1.2	100	0	40	100	0.0167	-0.667
1.1.3	100	0	75	100	0.04	-3.0
1.2.1	100	0	20	100	0.0125	-0.25
1.2.2	15	2	5	3	-0.50	2.50
1.2.3	100	0	20	100	0.125	-0.25
1.3.1	0.30	-0.20	.04	0.150	9.09	-0.364
1.3.2	100	0	30	0	-0.033	1.0
2.1	100	0	70	30	-0.025	1.750
2.2	0.30	-0.10	0.03	0.30	3.70	-0.11
2.3	1.00	0.00	0.20	1.00	1.25	-0.25
2.4	1.00	0.00	0.5	1.00	2.0	-1.0
2.5	1.00	0.00	0.4	0.7	3.33	-1.33
3.1	100	0	60	100	0.025	-1.50
3.2	\$30mil	\$10000	\$500000	\$30mil	0	-0.20
3.3	100	0	50	100	0.02	-1.0
3.4	100	0	40	0	-0.025	1.0
3.5	100	0	40	0	-0.025	1.0
3.6	48	1	18	3	-0.067	1.2
3.7	\$2.0mil	0	\$500000	0	0	1.0
3.8	100	0	20	0	-0.05	1.0

The matrix of bidding criteria preferences for the classification of ***Project factors*** are shown in Table 4-3 and the preferences of the classification *Company factors* in Table 4-4. Accompanying each matrix is the eigenvector determined with the maximum eigenvalue of the matrix.

Table 4-3: **Criteria preferences of classification *Project factors***

Bidding Criteria	Type	Size	Owner	Risk	Complex	Duration	Cash Flow Req'mnts	Estimate Uncertain
Type	1.0	1.0	0.1	0.1	0.5	2.0	0.5	0.5
Size	----	1.0	0.1	0.1	0.5	2.0	0.5	0.5
Owner	----	----	1.0	1.0	2.0	4.0	2.0	0.5
Risk	----	----	----	1.0	2.0	4.0	2.0	0.5
Complexity	----	----	----	----	1.0	2.0	3.0	0.5
Duration	----	----	----	----	----	1.0	0.5	0.1
Cash Flow Req	----	----	----	----	----	----	1.0	0.1
Est.Uncertainty	----	----	----	----	----	----	----	1.0

Maximum Eigenvalue = 9.1
Eigenvector = {0.05, 0.05, 0.21, 0.21, 0.10, 0.03, 0.07, 0.28}

Table 4-4: Criteria preferences of classification *Company factors*

Bidding Criteria	Current Workload	Req'd Rate of Return	Market Share	Overhead Recovery	Home Office Workload
Current Workload	1.0	2.0	2.0	2.0	4.0
Req'd Rate of Return	----	1.0	1.0	2.0	3.0
Market Share	----	----	1.0	2.0	4.0
Overhead Recovery	----	----	----	1.0	3.0
Home Office Wrkload	----	----	----	----	1.0

Maximum Eigenvalue = 5.1
Eigenvector = {0.35, 0.22, 0.23, 0.14, 0.06}

The matrix of sub-classifications for the classification of *Environment factors* is shown in Table 4-5, and the matrix of bidding criteria preferences for the sub-classifications of *Geographical*, *Economic* and *Historic factors* are shown in Tables 4-6, 4-7 and 4-8 respectively.

Table 4-5: Sub-classification preferences of *Environment factors*

Sub-classification	Geographical factors	Economic factors	Historic factors
Geographical	1.0	0.50	3.0
Economic	----	1.0	5.0
Historic	----	----	1.0

Maximum Eigenvalue = 3.0
Eigenvector = {0.31, 0.58, 0.11}

Table 4-6: Criteria preferences of sub-class. *Geographical factors*

Bidding Criteria	Location	Labor Reliability	Labor Availability
Location	1.0	2.0	1.0
Labor Reliability	----	1.0	0.5
Labor Availability	----	----	1.0

Maximum Eigenvalue = 3.0
Eigenvector = {0.40, 0.20, 0.40}

Table 4-7: Criteria preferences of sub-classification *Economic factors*

Bidding Criteria	Market Conditions	Competition	Future Projects
Market Conditions	1.0	2.0	5.0
Competition	----	1.0	4.0
Future Projects	----	----	1.0

Maximum Eigenvalue = 3.02
Eigenvector = {0.57, 0.33, 0.10}

Table 4-8: Criteria preferences of sub-classification *Historical factors*

Bidding Criteria	Historic Profit	Historic Failures
Historic Profit	1.0	5.0
Historic Failures	----	1.0

Maximum Eigenvalue = 2.0
Eigenvector = {0.83, 0.17}

The preferences of the bidding criteria are presented in Table 4-9 for the classifications of *Environment, Company*, and *Project factors*. The maximum eigenvalue and corresponding eigenvector is provided for each matrix under each table.

Table 4-9: Criteria preferences of classifications

Classifications	Environment Factors	Company Factors	Project Factors
Environment Factors	1.0	0.5	1.5
Company Factors	----	1.0	2.0
Project Factors	----	----	1.0

Maximum Eigenvalue = 3.0
Eigenvector = {0.28, 0.50, 0.22}

Saaty's method (1978) is then applied to determine a maximum eigenvector corresponding to the maximum eigenvalue of each matrix. The eigenvectors for each matrix represents the optimum scaling factors (W_j) for the members of the matrix and these are summarized in Table 4-10.

Table 4-10: Adjusted scaling factors from individual scaling factors

Class Block ID	Subclass Block ID	Criteria Block ID	W_i	W_i	y_i	S_i
1			28			
	1.1		31			
		1.1.1		40	y_1	3.47
		1.1.2		20	y_2	1.74
		1.1.3		40	y_3	3.47
	1.2		58			
		1.2.1		57	y_4	9.26
		1.2.2		33	y_5	5.36
		1.2.3		10	y_6	1.62
	1.3		11			
		1.3.1		83	y_7	2.56
		1.3.2		17	y_8	0.52
2			50			
		2.1		35	y_9	17.5
		2.2		22	y_{10}	11.0
		2.3		23	y_{11}	11.5
		2.4		14	y_{12}	7.0
		2.5		6	y_{13}	3.0
3			22			
		3.1		5	y_{14}	1.10
		3.2		5	y_{15}	1.10
		3.3		21	y_{16}	4.62
		3.4		21	y_{17}	4.62
		3.5		10	y_{18}	2.20
		3.6		3	y_{19}	0.66
		3.7		7	y_{20}	1.54
		3.8		28	y_{21}	6.16

Sum = 100

The adjusted scaling factors for all of the bidding criteria are summed to check the procedure. The sum of 100 is required.

An estimator selects the options for each bidding criteria representing company policy and specific project information. The options for each criteria are converted into utilities using the prescribed straight-line relationship of options and utility. The utility value is determined using the straight-line equation previously suggested and substituting the constants A and B from Table 4-2 for each bidding criteria. Each utility is then transformed to the common utility scale by a multiplication with the applicable adjusted scaling factor (S_j). The selected options, corresponding utility values, and common scale utility values for the project example are shown in Table 4-11.

Table 4-11: User selected options and corresponding utilities for bidding criteria

Criteria Block	Criterion Name	Selected Option	Straight-line Utility	S_i	Common Scale Utility
1.1.1	Location	yes	1	3.47	3.47
1.1.2	Labor Reliability	fair	0.166667	1.74	0.29
1.1.3	Labor Availabilty	easy	1	3.47	3.47
1.2.1	Market Conditions	average	0.375	9.26	3.47
1.2.2	Competition	6	-0.5	5.36	-2.68
1.2.3	Future Projects	average	0.375	1.62	0.61
1.3.1	Historic Profit	0.05	0.090909	2.56	0.23
1.3.2	Historic Failures	few	-0.66667	0.52	-0.35
2.1	Current Workload	medium	0.5	17.5	8.75
2.2	Req'd Rate Return	0.03	0	11.0	0
2.3	Market Share	0.70	0.625	11.5	7.19
2.4	Overhead Recov.	0.60	0.2	7.0	1.4
2.5	Home Off. Wrkld	0.50	0.333333	3.0	1.0
3.1	Project Type	yes	1	1.1	1.10
3.2	Project Size	400000	-0.184	1.1	-0.20
3.3	Owner	good	1	4.62	4.62
3.4	Other Risk	medium	-0.25	4.62	1.16
3.5	Project Complex	no	1	2.20	2.20
3.6	Project Duration	8	0.666667	0.66	0.44
3.7	Cash Flow Req	60000	0.88	1.54	1.36
3.8	Est. Uncertainty	medium	-1.5	6.16	-9.24

Eu = 28.3

The expected utility value (Eu) or total relative score is found by summing the final column of Table 4-11 (Common Scale Utility). The summation of this column is 28.3 (Eu), which is then transferred to the markup utility function to determine a recommended project markup.

The most common, smallest, and largest bid markup acceptable to the firm are input and assigned to the expected utility of the most preferred, threshold, and worst case scenarios of the criteria for the project. The following markups are assumed for the example:

1. most common = 5%
2. largest = 15%
3. smallest = 0.5%

The worst case selections for criteria is shown in Table 4-12 with the expected utility Eu_w.

Table 4-12: Expected utility for worst case selections

Criteria Block	Criteria Selection	Interpreted Scale	Straight-line u(y)	Adjusted factor Sj	Common Scale Utility
1.1.1	no	0	-1	3.8192	-3.82
1.1.2	poor	0	-0.66667	1.4756	-0.98
1.1.3	impossible	0	-3	3.3852	-10.16
1.2.1	few	0	-0.25	9.2568	-2.31
1.2.2	15	15	-5	5.3592	-26.80
1.2.3	few	0	-0.25	1.624	-0.41
1.3.1	-0.2	-0.2	-2.18182	2.5564	-5.58
1.3.2	many	100	-2.33333	0.5236	-1.22
2.1	high	100	-0.75	17.5	-13.13
2.2	-0.1	-0.1	-0.48148	11	-5.30
2.3	0	0	-0.25	11.5	-2.88
2.4	0	0	-1	7	-7.0
2.5	0	0	-1.33333	3	-4.0
3.1	no	0	-1.5	1.1	-1.65
3.2	10000	10000	-0.1996	1.1	-0.22
3.3	poor	0	-1	4.62	-4.62
3.4	high	100	-1.5	4.62	-6.93
3.5	yes	100	-1.5	2.2	-3.3
3.6	48	48	-2	0.66	-1.32
3.7	2.00E+06	2.00E+06	-3	1.54	-4.62
3.8	high	100	-4	6.16	-24.64
				Eu =	-130.91

The scenario for the the most preferred options is shown in Table 4-13 where the Eu_p is derived.

Table 4-13: Expected utility for most preferred selections

Criteria Block	Criteria Selection	Interpreted Scale	Straight-line u(y)	Adjusted factor Sj	Common Scale Utility
1.1.1	yes	100	1	3.8192	3.82
1.1.2	good	100	1	1.4756	1.48
1.1.3	easy	100	1	3.3852	3.39
1.2.1	many	100	1	9.2568	9.26
1.2.2	3	3	1	5.3592	5.36
1.2.3	many	100	1	1.624	1.62
1.3.1	0.15	0.15	1	2.5564	2.56
1.3.2	none	0	1	0.5236	0.52
2.1	low	0	1.75	17.5	30.63
2.2	0.3	0.3	1	11	11.0
2.3	1	1	1	11.5	11.5
2.4	1	1	1	7	7.0
2.5	0.7	0.7	1	3	3.0
3.1	yes	100	1	1.1	1.1
3.2	3.00E+07	3.00E+07	1	1.1	1.1
3.3	good	100	1	4.62	4.62
3.4	low	0	1	4.62	4.62
3.5	no	0	1	2.2	2.2
3.6	3	3	1	0.66	0.66
3.7	0.00E+00	0.00E+00	1	1.54	1.54
3.8	low	0	1	6.16	6.16
				Eu =	113.14

The final scenario is the threshold point selections which result in an expected utility of 0 (Eu_t). The expected utility values from each scenario are used to solve for the constants of the markup utility equations 4.7 and 4.8 as follows:

$$0.5\% = M(Eu_p) = M(113.14) = 113.14C + D$$

$$5\% = M(Eu_t) = M(0) = (0)C + D$$

and likewise

$$15\% = M(Eu_w) = M(-130.91) = -130.91G + H$$

$$5\% = M(Eu_t) = M(0) = (0)G + H$$

which reduces to:

If Eu greater than 0 then the project markup is = Eu(-0.04) + 5.0

Otherwise the project markup is = Eu(-0.08) + 5.0

This markup function has been previously shown in Figure 4-5.

Since the Eu from input selections (Table 4-11) is 28.3 the former function applies and the recommended project markup is calculated to be 3.9 %.

4.9 Conclusions

The utility theory model developed and implemented in ICBS demonstrates an application of a multi-criteria analysis which uses subjective and quantitative information in completing an objective. The model successfully determines a bid markup for a construction project considering all types of bidding criteria.

The utility theory model discussed is self-calibrating as it uses a contracting firm's past markup values in the determination of a recommend bid markup. The automation of the model reduces the labour intensive number crunching which is required for implementation of utility theory.

Chapter 5: A Prototype Implementation of ICBS

5.1 Introduction

This chapter describes how the individual markups determined by the three bidding models are combined to form a single markup. The combining of these markups accommodates most of the bidding strategies adopted by contracting companies. The markup produced by the probability theory model accommodates the bidding strategy which considers the competitive environment. The markup produced by the utility theory model accommodates a bidding strategy that determines a markup based on satisfaction and attractiveness of a project. Finally, the markup resulting form the cash flow model accommodates a bidding strategy which determines a markup based on the internal cash requirements of a company. In the cash flow model a minimum required rate of return should be used so that the model produces a result that represents the minimum acceptable markup for a project. The combination of the results from each bidding model allows for the combination or variation of the standard bidding strategies. The implementation of the ICBS prototype is discussed along with a program description which illustrates the user interface. The use of a systematic or mathematical bidding system has been previously hindered by the 'number crunching' and updating required to maintain its usefulness. To reduce these drawbacks, the bidding models used in this research have been automated.

5.2 Determination of Project Markup

Each of the three bidding models produces a markup based on the models theory of analysis (M_p is the markup from the Carr model, M_c is the markup from the cash flow model, M_u is the markup from the utility theory model). These individual markups may be combined by ICBS to produce a single recommended markup. The recommended markup is determined using one of two approaches. The first approach considers the magnitude of the markup from each of the different bidding models and compares the magnitudes with the bidding strategy that the markup represents. The second approach applies weighting factors to the markups produced by each of the three bidding models to produce a weighted average. The weighting factors are obtained from various preferences of bidding strategies.

5.2.1 Project Markup from Strategy and Magnitude

The magnitude of each of the recommended markups is compared to select the appropriate markup to use. The comparison technique uses a set of rules to perform the evaluation and select a markup without compromising the results produced by any of the bidding models (no average used). The rules are listed as follows:

Rule 1. Compare M_p to M_c
Rule 2. Compare M_p to M_u
Rule 3. Compare M_u to M_c

The procedure and order for applying the rules is summarized in the decision tree shown in Figure 5-1.

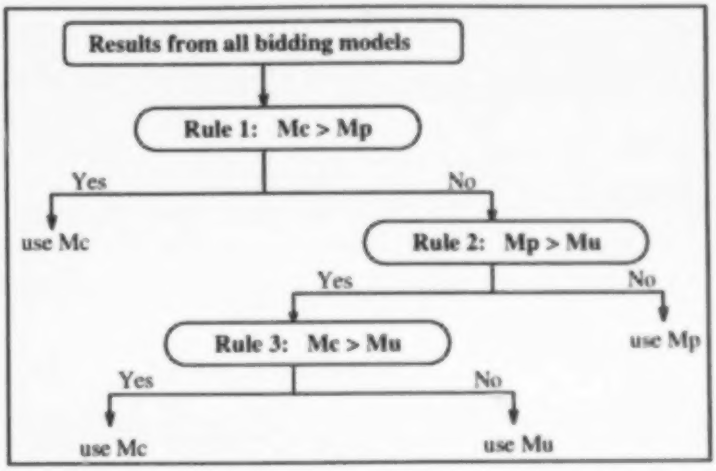


Figure 5-1: Decision tree for applying combining markup rules.

The application of Rule 1 indicates whether the current market will allow the company to meet its minimum requirements. If the markup from the probability model is less than the markup from the cash flow model then the market will not sustain the minimum company requirements and it is recommended that the company not bid. However, if the company wishes to submit a bid it is recommended that the cash flow model markup be used. If M_p is larger than M_c then the current competitive environment will support the company's minimum requirements and the application of Rule 2 proceeds. This rule checks to see if the current market will support the satisfaction or attractiveness of the project by comparing the markup from the probability model to the markup of the utility theory model. If M_u is larger than M_p then the market will not sustain the attractiveness of the project and it is recommended that the markup from the probability model be used. However, if M_u is less than M_p then the competitive environment will support the attractiveness of the project and the application of Rule 3 proceeds. This rule checks to see if the attractiveness of the project meets the minimum requirements of the company by comparing M_c to M_u. For this rule the larger of the two markups is used.

5.2.2 Project Markup from Weighted Average

The markups from each of the three bidding models can be combined using a weighted average technique. The recommended markup is calculated by applying weighting factors (W_j) to each bidding model markup (M_j) as shown in equation 5.1.

$$Markup = W_c M_c + W_u M_u + W_p M_p \tag{5.1}$$

The weighting factors are determined using the preference optimizing technique developed by Saaty (1978) which was introduced in Chapter 4. The preferences are derived from the bidding policy of the company. This research assumes the preferences between each of the bidding methodologies is known, but the development of an expert system to derive these preferences based on bidding strategies can be completed in a future study.

The preferences are selected from the numerical scale of {0,0.1,0.5,1,1.5,2,3,4,5} and organized in a square matrix as shown in Table 5-1 where the different bidding strategies are the column and row headings.

Table 5-1: Organization of preferences of bidding strategies

	Company Requirements	Company Satisfaction	Competitive Environment
Company Requirements	1.0	0.5	2.0
Company Satisfaction	------	1.0	3.0
Competitive Environment	------	------	1.0

For the matrix above the *company internal requirement* strategy is half as preferred as the *company satisfaction* strategy and twice as preferred as the *competitive environment* strategy. The *company satisfaction* strategy is 3 times as preferred as the *competitive environment* strategy. All the entries along the diagonal of the matrix are 1.0 since a bidding strategy cannot be preferred more or less than itself. No entries are required below the diagonal since these are the reciprocal of the upper triangle of the matrix. The preferences in the matrix of Table 5-1 would indicate that the bidding strategy for determining the markup is to place a high priority on considering all bidding criteria while favoring recovery of company internal requirements rather than the adopting allowances of the current competitive bidding market. The maximum eigenvalue of the matrix above is 3.0, and the corresponding eigenvector is {0.30, 0.54, 0.16}. The various bidding strategies directly correspond to one of the bidding models and hence the eigenvector of the strategy preferences matrix can be applied as weighting factors to each of the bidding model markups. The eigenvector is distributed as weighting factors for the bidding models as follows; weighting factor for cash flow model (W_c) is 30, weighting factor for utility theory model (W_u) is 54, and the weighting factor for Carr's model (W_p) is 16. The weighting factors are then applied to the individual model markups by applying equation 5.1.

5.3 Implementation of ICBS

ICBS is separated into the three different bidding models that have been incorporated into the system. Along with these models is the supporting data management system to allow for the retrieval of information required by the model. The structure of the ICBS prototype is shown in Figure 5-2.

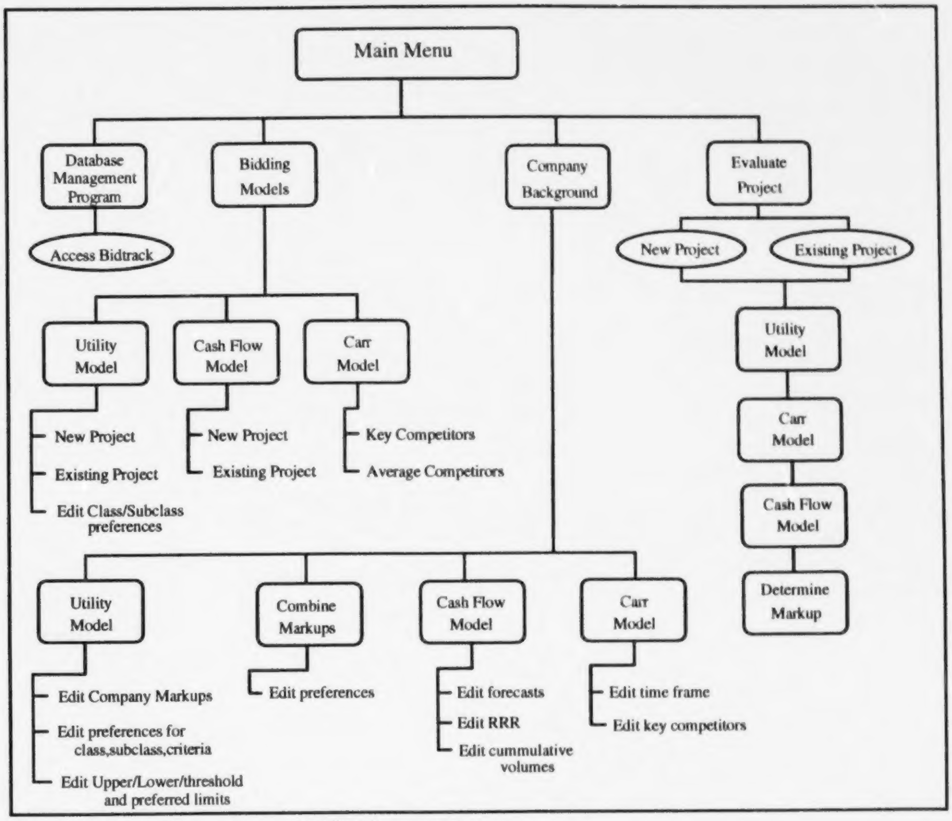

Main Menu
Database Management Program
Access Bidtrack
Bidding Models
Utility Model
New Project
Existing Project
Edit Class/Subclass preferences
Cash Flow Model
New Project
Existing Project
Carr Model
Key Competitors
Average Competirors
Company Background
Utility Model
Edit Company Markups
Edit preferences for class,subclass,criteria
Edit Upper/Lower/threshold and preferred limits
Combine Markups
Edit preferences
Cash Flow Model
Edit forecasts
Edit RRR
Edit cummulative volumes
Carr Model
Edit time frame
Edit key competitors
Evaluate Project
New Project
Existing Project
Utility Model
Carr Model
Cash Flow Model
Determine Markup

Figure 5-2: Structure of ICBS prototype

The implementation of the utility model is accomplished by using numerous data files to store the combining preferences of bidding criteria and an ISAM database table (Indexed Sequential Access Method) to store the limits, threshold and most preferred points for all of the bidding criteria. Each classification of sub-classification of criteria has a data file containing the preferences for combining the bidding criteria within the group. Similarly, for the sub-classification and classification headings there is a data file containing the preferences which are used to determine adjusted weighting factors of the bidding criteria. These preference data files are sensitive to their order and updating is best performed from within ICBS rather than manually editing. The data files containing preferences have the extension *".prf"*. The utility functions for each bidding criteria are produced using the methods and equations described in Chapter 4 along with the limits and points retrieved from the ISAM table. The scaling factors are calculated using the information retrieved from each preference data file, and these are immediately adjusted by the class and sub-class scaling factors. The utility values are derived from the user inputs and the utility functions and scaling factors are applied. The summation is taken to determine the expected utility of the project. The markup function is derived from the common markups of the company which are retrieved from the background data file and expected utility values of the most preferred, worst case, and threshold points is calculated. The worst case points are taken as either the upper or lower limits of the bidding criteria. The absolute value of the difference between the upper limit and the most preferred point is calculated as well as the difference between the lower limit and the most preferred point. The worst case point is the limit with the largest difference from the most preferred point. The expected utility of the project is applied to the markup function and the bid markup for the project results.

The implementation of the cash flow model is accomplished by retrieving the company requirements of return on investment along with forecasted and current workloads to determine the amount of home office overhead to apply to the project. The cost per period for each category is stored in one dimension arrays. The present value of the project costs is calculated using the equations discussed in Chapter 3. The summation of the present value for the individual categories is determined to produce the total present value of cash outflow. The individual cost categories are summed to obtain the total cost per period of the project and the home office overhead amount is deducted from the cost per period. The billing factors for each period cost are applied and the retainage is deducted to obtain an invoice amount. The invoice amount is lagged by the payment policy and the present value factors are applied to obtain the present value of cash inflow. The ratio of present value of cash outflow over the present value of cash inflow is taken to produce the bid markup.

The implementation of Carr's model is accomplished by retrieving historical bidding data using the ISAM database table updated by the database management program, Bidtrack (AbouRizk et. al. 1993). Carr's model is implemented for the two scenarios: evaluation of specific competitors and evaluation of average competitors. For the specific competitor scenario the competitors are specified and the database is searched retrieving projects that each competitor has previously bid on. For each retrieved project the distribution of cost estimate to average cost estimate is determined as well as the ratio of competitor's bid price to the cost estimate. Histograms for each competitor are constructed for each set of ratios using Sturges' rule to determine the cell width of the histogram. The prototype calculates the cost estimate for each project using equation 5.2 since this value is currently not provided in the Bidtrack database.

$$\textit{Cost Estimate} = \textit{Firm's Bid} - \textit{ABS(Firm's Bid - Average Bid)} \tag{5.2}$$

The probability distribution functions (PDF) are constructed from the histograms of the bid/cost ratios (B/C) and cost estimate/average cost estimate ratios (C/C). Determination of the probability of winning against each competitor is found from the area under each PDF of B/C ratios. The probabilities of winning over each competitor are combined using either Friedman's method or Gates', method. Then the expected value is derived using equation 2.7. The bid markup is increased by one cell width of the B/C histogram and the probability of winning over for all competitors is redetermined as is the expected value. The bid price is continually adjusted until the highest B/C ratio has been reached. The bid price producing the highest expected value is selected as the optimum markup.

For the scenario of average competitors a specified time frame is used to search the database for all projects since the cut-off date. Distributions of average bid/cost ratio and average cost estimate to cost estimate ratios are developed. Each distribution is standardized by a single standard deviation and the methodology for determining the optimum bid price is similar to the previous scenario.

5.4 Program Description

The procedure of the ICBS prototype is summarized in the algorithm format as follows:

1. Application of utility theory model.
2. Application of Carr's model.
3. Application of cash flow analysis model.
4. Combination of markups from each model.

In addition to the above algorithmic procedure the ICBS prototype allows an estimator to access individual models and determine the markup for a project, or update the company background policy information.

Each section in the structure of Figure 5-2 is represented by a menu in the program. All menus in the program have an option to return to the previous menu except the main menu which provides the option of terminating the session. From the main menu, shown in Figure 5-3, the option of *'evaluate a project'* will apply all three bidding models to a project and produce a recommended markup using equation 5.1.

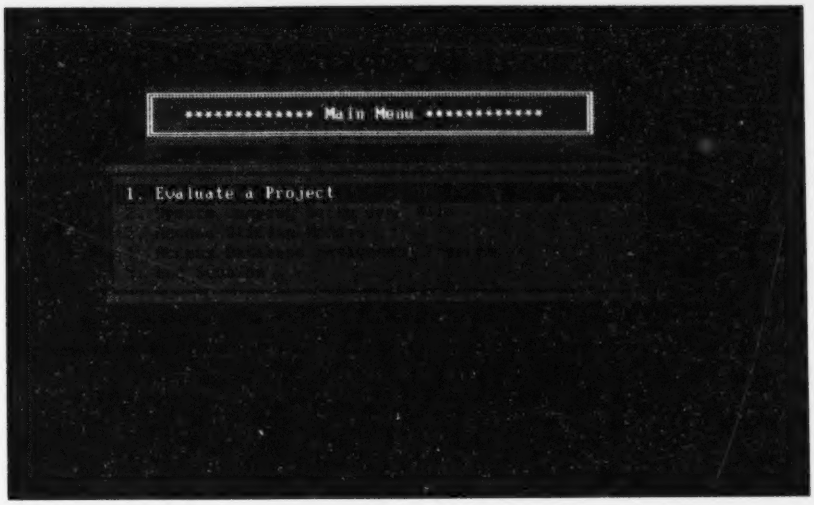


Figure 5-3: Main menu of ICBS

The selection of the *'database management program'* from the main menu transfers the user to the Bidtrack program (AbouRizk et. al. 1993). This program contains the capabilities of updating the historical database which is used in Carr's model.

ICBS organizes and maintains the company background information that is used by each of the bidding models. The selection of *'update company background'* from the main menu produces the background information menu shown in Figure 5-4. From this menu the information required by the different bidding models can be viewed and edited by selecting each model's option from the menu.

The program provides the facility to apply each bidding model individually which can be invoked by selecting *'access bidding models'* from the main menu. Selection of this option produces the bidding models menu shown in Figure 5-4. This menu provides the user with options of invoking each of the three bidding models or combining the three models to produce a recommended markup. The combining option requires that each bidding model markup be predetermined. The bidding model markups are combined using weighting factors and applying equation 5.1.

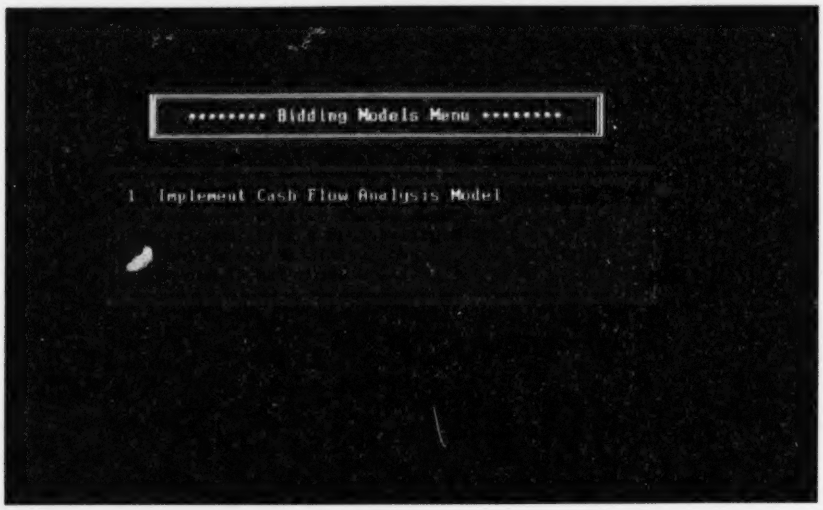

******** Bidding Models Menu ********
1 Implement Cash Flow Analysis Model

Figure 5-4: Bidding models menu of ICBS

Selecting the *'utility theory model'* from the bidding models menu produces the utility theory model menu shown in Figure 5-5. This menu provides the options of reviewing a previous program, evaluating a new program, editing the classification, editing sub-classification preferences and editing the company markup values.

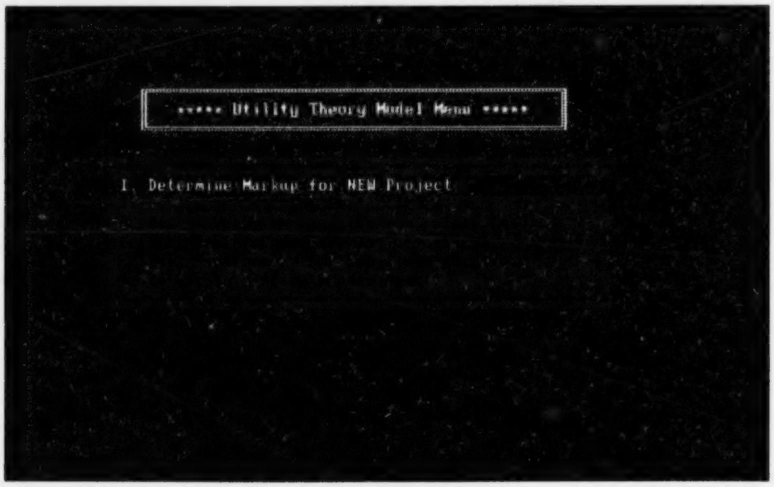

***** Utility Theory Model Menu *****
1. Determine Markup for NEW Project

Figure 5-5: Utility theory model menu

For the *'determine markup for a new project'*, selection the system solicits the project name and proceeds to request input on each of the 21 bidding criteria identified in the utility theory model. For criteria requiring subjective input a menu of possible options is presented as shown in Figure 5-6. Other numerical input is made manually.

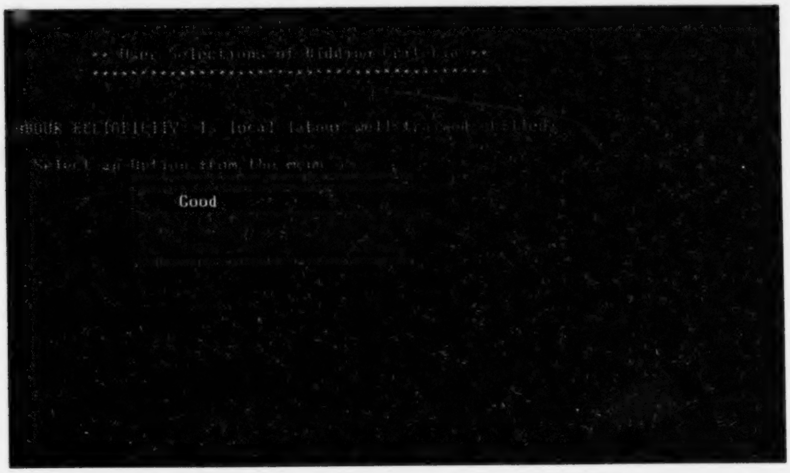


Figure 5-6: Subjective input for bidding criteria Labor Reliability.

After all bidding criteria selections have been input, the program determines each criteria utility function and adjusts it according to the preferences from the background information. The markup function is derived and the markup for the utility theory model is calculated.

The cash flow analysis model can be invoked from the bidding models menu and the presentation of the cash flow menu results as shown in Figure 5-7. From this menu the option of evaluating a new project or reviewing a previous project can be selected.

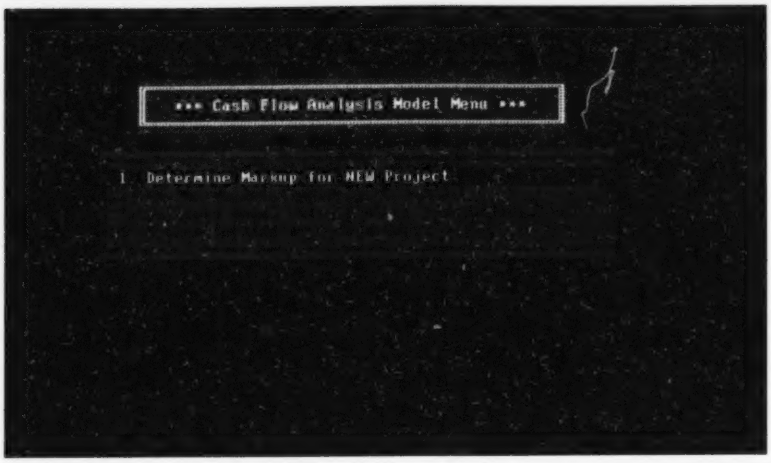

*** Cash Flow Analysis Model Menu ***
1. Determine Markup for NEW Project

Figure 5-7: Cash flow analysis model menu

The selection of *'determine markup for new project'* requests the project name from the user. This creates a data file where all new project information will be stored. The project information such as duration, payment policy, and holdback. is requested along with the costs of the individual categories. All category costs are entered on a per period basis while the labour category costs are input on a bimonthly or half period basis. When the project information has been entered, the system calculates the markup according to the cash flow analysis model previously described.

The selection of the Carr model from the bidding model menu presents the user with the option of analyzing specified key competitors or analyzing average competitors. If the option of key competitors is selected then a menu of competitors appears and the desired key competitors are selected. The current historical database does not contain any estimated costs and therefore a formula to calculate an estimated cost for the project is used. The derivation of project cost estimate will only affect the academic application since cost estimates of a company are known and would be included in an updated database. The next input required is the method of combining the individual probabilities of winning. The choice of the methods described by Friedman (1956) or Gates (1967) is offered and the selected method is used to combine the probability of winning against each competitor. The markup is calculated using the Carr model.

5.6 Development Environment

The automated bidding system has been developed using the Basic Professional Development System (BC71) software and operates on personal computers with a DOS system. Additional software is required to support the program is the ISAM engine (included in BC71). The program uses several routines from the QuickPack Professional Library (Crescent Software 1988) to enhance the user interface and improve processing speed.

5.7 Conclusions

The Monte Carlo study program has been validated using the ICBS program where the same results were returned as generated by a Monte Carlo simulation. The example applications of the sensitivity analysis model has been confirmed by an individual run of the cash flow model. The utility theory example problem has also been confirmed by an individual run of the automated utility theory model. Currently, the historical database does not contain numerous projects for one specific competitor and therefore a well defined B/C distribution is not obtained. The use of Carr's model is limited by the number of projects retrieved from the current database and the cost estimate assumptions used. A real world implementation would avoid these restrictions as the amount of information increases the accuracy and output of the model become more defined.

Chapter 6: Final Discussion

A construction company may have different considerations and attitudes which will effect the bid markup to be applied to a construction tender. Several of these bidding attitudes are difficult to assess and hence a bidding model based on utility theory has been developed to assist a company in the quantification of bidding criteria which are normally evaluated on a subjective scale. The utility theory bidding model produces a bid markup which represents the company's satisfaction towards the project at the time of bidding. A bidding model based on present value concepts has also been developed to determine a bid markup based on the cash flow of the project and cost distribution. A sensitivity analysis has been performed on the cash flow model using the Monte Carlo technique to show the models sensitivity to input variables. It was found that the markup determined by the cash flow model is sensitive to changes in external variables such as required rate of return, holdback amount and project payment policy. It was also shown that the cash flow model is not significantly sensitive to changes in the internal factors of the project.

Previous research has provided industry with tools to determine a bid markup based on specific bidding strategies. The Integrated Construction Bidding System provides a tool which can accommodate a variation of these bidding strategies by integrating the results of various bidding models. The utility theory bidding model along with the cash flow model and Carr's probability model have been combined to produce a bidding system which accommodates most bidding strategies used in the construction industry. Each bidding model represents a bid strategy and therefore when the results of the bidding models are combined each strategy of bidding is integrated. The results from the bidding models can be combined using a weighted average method or a magnitude evaluation technique.

The future development of ICBS and future research possibilities are numerous since the research discussed is a relatively new application. A sensitivity analysis should be performed on the utility theory model to explore the models sensitivity to input changes. Also, utility functions should be developed to represent the bidding criteria using a relationship other than linear to explore differences in representations. A set of rules and heuristics can be developed to complete an expert system to assist the user in determining the preferences for combining the results from the different bidding models. ICBS should be tested in a gaming environment, its performance evaluated, and its preferences recalibrated. ICBS should then be tested in a real world environment along side current methods used by a company. The measure of performance in the testing procedure could be the success rate of bids submitted.

The automation of ICBS is an effective method to study the effects of changes in the bidding strategy or project details to the bid markup. The automation process allows access to bidding models regardless of the users strengths or weaknesses in mathematics or statistics which has been a deterrent for most bidding models in the past.

The use of information management with bidding models is a practical application which will provide a strategic tool for companies involved in competitive bidding. The historical information can be rapidly retrieved and manipulated which will give a competitive edge to the user.

The development and incorporation of expert system technology is encouraged by most major industries where "*there is no substitute for experience*". ICBS conceptualizes an application of expert system technology to the construction industry in which it is linked to a database of historical information via bidding models. The bidding tool developed will provide companies with efficient method by which to accomplish the basic objective of "maximize profit and remain low bidder on a project."

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Appendix A: Algorithms of Bidding Models and Monte Carlo Study

Algorithm for Utility Theory Model

Input from user:

- Selections for all of the bidding criteria.

Information Retrieved from background files.

- limits of criteria selections
- threshold and most preferred points of criteria selections
- preferences of each bidding class or sub class
- preferences of bidding criteria within each class or sub class
- company common markups, normal, high, low

Determine Adjusted Scaling Factors

- retrieve preferences for each class of criteria
- perform Saaty's method to determine scale factors
- retrieve preferences of class and sub class
- perform Saaty's method to determine scale factors
- adjust scale factor of criteria by class and sub class factors.

Determine scaled utility functions of bidding criteria

- derive utility values of criteria selections from the retrieved utility functions
- adjust utility values by adjusted scaling factors
- expected utility = sum all adjusted utility values

Determine Markup

Retrieve markup function
apply expected utility to markup function to determine markup.

END

Algorithm for the Cash Flow Analysis Model

Information of Project Contract Details:

- # of payment periods.
- total cost estimate
- costs per period per category stored in arrays
- billing policy factor (%)
- retainage specified by contract
- contract payment policy (days)

Information retrieved from company policy and background:

- Required rate of return (annual or monthly).
- annual projected indirect overhead
- annual projected work volume $
- recovered indirect overhead
- obtained work volume

Determine Home Office Overhead

- Retrieve current work volumes and recovered overhead
- Retrieve forecasts
- derive HOOH rate = Overhead/ Work Volume
- Apply rate to total project cost and determine amount of HOOH per period

Determine Present Value of Cash outflows (labor category)

```
•  PVlabor = 0
•  FOR i = 1 to (2 times duration)     'bimonthly
      PVfactor = 1 /((1 + RRR) ^ (i/2))
      PVlabor = PVlabor + (labor(i) * PVfactor)
```

Determine Present Value of Cash outflows (material and equipment category)

```
•  PVmat = 0
•  FOR i% = 1 to (duration)     'monthly
      PVfactor = 1 /((1 + RRR) ^ (i%+0.5))  'cost occurs at middle of period
      PVmat = PVmat + ((material(i%) + equip(i%))* PVfactor)
```

Determine Present Value of Cash outflows (PRB, IOH, operating costs category)

```
•  PVioh = 0
•  FOR i% = 1 to (duration)     'monthly occurence
      PVfactor = 1 /((1 + RRR) ^ (i%)  'cost occurs at end of period
      PVioh = PVioh + ((ioh(i%) + prb(i%)+oper(i%))* PVfactor)
```

Determine total present value of cash outflow

- PVout = PVioh + PVlabor + PVmat

Determine the present value of Cash Inflows (total per period)

```
    •  derive period cost (summation of all arrays)
    •  lagtime = paypolicy *1.5/30  ' convert workdays
    •  temp = cost initial - HOOH
    •  retainage = holdack * temp
    •  PVinflow = (temp - retainage ) * PVfactor usinbg period = lagtime
    •  For  i = 1 to duration
            charge =  periodcost - HOOH
            billable = Billing Factor(this period) * charge
            retainage = retainage + (billable * holdback)
            invoice = billable - ( billable * holdback)
            PVfactor = 1 /((1 + RRR) ^ (i + lagtime))
            PVperiod inflow = PVfactor * invoice
            PVinflow = PVinflow + PVperiod inflow

Release holdack
    •  Release = Time for release / 30 ' convert release of holdback time to periods
    •  PVinflow = retainage * 1 /((1 + RRR) ^ (duration +release))

Calculate recommended Markup:
  •  markup = PVoutflow / PVinflow -1

END
```

Algorithm for the Monte Carlo Study for Sensitivity Analysis of Cash Flow Model

This algorithm utilizes the cash flow algorithm and corresponding code to complete the Monte Carlo study of the sensitivity and accuracy of the model to changes in external and internal parameters.

All external variables remain fixed during the sensitivity analysis except for the test variable which is changed after each set of 40 runs.
defaults: holdback = 15%, Payment policy = 20 days, RRR= 2.5%
All internal variables (cost categories) are randomly generated except the test variable which remains fixed between each set of 40 runs.

Input external variable or internal category sensitivity study.
Input from the user the amount of the test variable and alter its default value if required.

Repeat procedure for 40 runs:

Randomly generate duration of project from uniform distribution [3-25]
Randomly generate project total cost from uniform distribution [0.5mil,20mil]
- intial cost = 0.15% of the total cost and calculate new project cost.
- Store the duration and project cost in their array for each run.

Generate the mode point for the triangluar distribution (for project cost curve)
- mode derived randomly from uniform distribution 30 to 70% of total duration.

Generate project S-curve from triangular distribution: for each period
- if y < middle point then Cummualtive cost (period)= total cost*(y)^2/(middle)*(upper)
- else Cummualtive cost (period) =totalcost*(upper-y)^2/ (upper -middle) *(upper)

For External variable sensitivity test:
Randomly generate cost categories: six different cost categories from uniform distributions
- labour = 0.1 to 0.5
- material = 0.1 to 0.5*(1-labour) 'remaining amount
- prb = prb rate * labour
- remaining = 1 - prb-labour-material
- equipment = (0.1 to 0.5) * remaining
- operate = (0.1 to 0.5) * (remaining - equipment)' update remaining
- indirectOH = remaining - equipment - operate

For Internal variable sensitivity test
Randomly generate cost categories:for other 5 cost categories from uniform distributions
- remaining = 1 - amount of test variable
- remove calculation of test variable amount from the listed categories
- labour = (0.1 to 0.5) * remaining
- material = 0.1 to 0.5*(remaining - labour)

```
        •   prb = prb rate * labour
        •   remaining = remaining - prb-labour-material
        •   equipment = (0.1 to 0.5) * remaining
        •   operate = 0.1 to 0.5 ) * (remaining - equipment) ' update  remaining
        •   indirectOH = remaining - equipment - operate
Determine cost of period 1 for each cast category: store in category array
        •   Material(1) = material * Cummualtive Cost (1)
        •   Equipment(1) = equipment * Cummualtive Cost (1)
        •   PRB(1) = prb * Cummualtive Cost (1)
        •   Operate(1) = operate * Cummualtive Cost (1)
        •   IOH(1) = indirectOH * Cummualtive Cost (1)
        •   Labour(1) = labour * Cummualtive Cost (1) *0.5          'split 50/50 bimonthly
        •   Labour(2) = labour * Cummualtive Cost (1) *0.5
Determine category cost of remaining periods:     for period 2 to duration of project
        •   PeriodCost(period) = Cumulative cost(period) - Cummulative cost(period-1)
        •   Material(period) = material *PeriodCost(period)
        •   Equipment(period) = equipment *PeriodCost(period)
        •   Operate(period) = operate *PeriodCost(period)
        •   PRB(period) = prb *PeriodCost(period)
        •   IOH(period) = indirectOH *PeriodCost(period)
        •   Labour(2*period) = labour*0.5*PeriodCost(period)
        •   Labour(2*period-1) = labour*0.5*PeriodCost(period)

Enter Cash Flow Analysis Model to calculate markup

Record Markup in array

BACK to Repeat for 40 runs

Output Results for each of the 40 runs:
        •   run number, total project duration , total cost, test variable value
Calculate statistics
        •   average, variance, 95% confidence interval
        •   output statistics
END
```

Algorithm for Carr's Bidding Model (1982)

```
Input form User:
    •   project estimate
    •   time frame for evaluation (how far back in time)
    •   method to use:
                option A: Evaluate for specific competitors
                        Combine probabilities using Gates or Friedmans Method..
                option B: Evaluate for average competitors.
For method Option A:
    •   Input from User: number of contractors to be evaluated.
    •   For all contractors
            1.  Input name of specific contractor
            2.  DO until project date < time frame specified
                    •   Retrieve project
                    •   Search contractors name,
                    •   IF found search firm's name
                            IF found then count number of projects
                                    Retrieve NumberBidders
                                    Retrieve biiders price
                                    find mean bid
                                    find cummulative cost estimate
                    •   ELSE, retrieve next project
            5.  LOOP
            6.  Determine MeanCostEst
            7.  Determine C/C and B/C ratios for each project.
    •   Construct B/C & C/C distributions
            1.  NumCells(j) = 1 : Sturgess Rule.
            2.  Construct Histogram: FOR all projects
            3.  Construct PDF

    •   Detemine Area under C/C PDF
    •   Initialize firms bid ratio and increment:
            1.  FBC = minimum B/C ratio from all projects
    •   Determine Probability of Winning
            1.  Find area under PDF and right of FBC
    •   Combine Probabilites according to Friedman or Gates:
            1.  IF Friedman then: FOR temp% = 1 to NumContractors
                    Prob = Prob*ProbTotal(temp%): NEXT temp%
            2.  IF Gates then FOR temp% = 1  to NumContractors
                    tempsum = tempsum + ((1 - ProbTotal(temp%))/ProbTotal(temp%)) :
                        NEXT temp%
            3.  Prob = 1/(1+tempsum)    'Gates only
    •   Calculate Expected Value:
            1. EV = (FBC -1) * Prob * CostEst
            2. maintain maximum expected value
            3. INcrease FBC and repeat EV calc and probability calc.
```

For method Option B:

```
    • User INPUT 'Expected number of bidders : ExpectNum
    • DO until project date < time frame specified
            1. Search for Firm's Bid. (if firm did not bid then don't consider project)
            2. IF firm = found THEN
                    • Retrieve NumberBidders(NumProj)
                    • Get prices for each bidder
                    • Determine MeanProjBid
                    • Determine CummMeanBid = CummMeanBid + MeanProjBid
                    • CummCostEst = CummCostEst + CostEstimate(NumProj)

    • Determine averages for all projects
            1. MBC = CummBC / CummBidders
            2. MeanCE = CummCostEst / NumProj
            3. MeanBid = CummMeanBid / NumProj
            4. Standardize Values by standard deviation.
    • Determine satndardized mean cost estimate
• Determine standard deviation (using CostEst/ MeanBid Ratio)
• Determine the Cost Estimate / Mean Cost Estimate Distribution
    1. NumCells from Sturgess Rule
    2. Construct Histogram: FOR j = 1 to NumProj
    3. Construct PDF : FOR k = 1 to NumCells
•   Find area under PDF
•   Determine standardized B/C distribution
    1. Construct Histogram: FOR l = 1 to NumProj
    2. Construct PDF : FOR k = 1 to NumCells
•   Determine Optimum FBC
•   Determine Probability of Winning
    1. find area beneath PDF and right of FBC
• Determine Expected Value
            1. EV = (FBC -1) * Prob * ProjectEstimate "*detemine expected value
            2. maintain maximum expected value
            3. increase FBC and repeat process
• output results
END
```

Appendix B: Sensitivity to Required Rate of Return

Monte Carlo Study for Sensitivity Analysis of Cash Flow Model to RRR

The required rate of return (RRR) is varied from 0% per month to 10% per month with the recommended markup determined by the cash flow analysis model. The values for other variables which are held constant are shown below. The monte carlo study is simulated for 40 runs randomly generating project duration, total cost and cost distribution for each run. The results for each 40 run simulation are shown in Tables B-3 to B-9 with the average markup, standard deviation and 95% confidence interval calculated for each table. A summary of the Monte Carlo study is shown in Table B-1.

External Variables:

Payment Policy =	20 wk dys
RRR =	variable
Holdback =	15%
Billing Factor =	1.0

Payroll Burden is 24% of labour amount

Table B-1: Summary of Monte Carlo study for RRR

RRR (%)	Average Markup (%)	Confidence Interval	Upper Limit	Lower Limit
0	1.3	0.03	1.33	1.27
0.5	2.3	0.07	2.37	2.23
1	3.2	0.12	3.32	3.08
2	5.0	0.26	5.26	4.74
5	11.0	0.59	11.59	10.41
7	14.3	0.98	15.28	13.32
10	19.4	1.04	20.44	18.36

The quantile quantile (q-q) plot is produces for each 40 run simulation to check for normality. If the plot presents a linear pattern then the accuracy of the 95% confidence interval is proved. The data for the q-q plots is contained in Table B-2 with the plots shown in Figures B-1 to B-7.

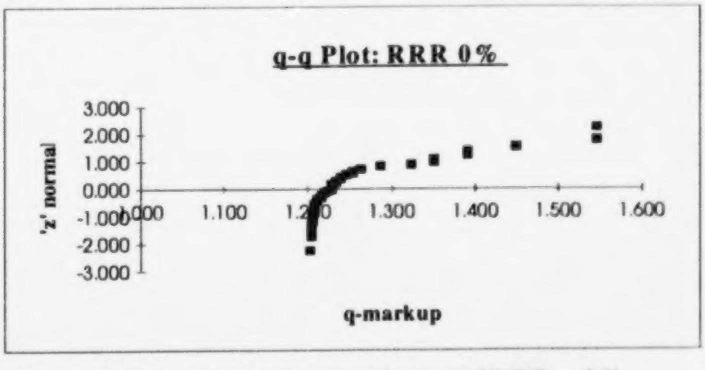

Figure B-1: Q-Q plot for simulation of RRR = 0%

Table B-2: Data for quantile-quantile plots for RRR analysis

	Required Rate of Return (%), (X)								
#	0%	0.5%	1%	2%	5%	7%	10%	Phi	'z' (Y)
1	1.203	1.962	2.458	3.813	7.357	8.560	12.343	0.013	-2.240
2	1.205	2.007	2.643	3.823	7.842	9.966	13.417	0.038	-1.780
3	1.205	2.054	2.654	3.916	7.874	10.043	14.586	0.063	-1.535
4	1.205	2.066	2.735	3.920	8.383	10.393	14.658	0.088	-1.355
5	1.207	2.072	2.739	3.931	8.562	10.780	15.692	0.113	-1.213
6	1.207	2.080	2.784	4.044	8.568	10.982	15.956	0.138	-1.092
7	1.207	2.085	2.820	4.046	8.804	11.025	15.975	0.163	-0.985
8	1.207	2.098	2.836	4.088	9.055	11.422	16.731	0.188	-0.888
9	1.209	2.112	2.838	4.115	9.471	11.728	16.741	0.213	-0.798
10	1.209	2.125	2.844	4.217	9.514	11.982	17.143	0.238	-0.715
11	1.209	2.147	2.875	4.252	9.540	11.987	17.293	0.263	-0.635
12	1.209	2.158	2.905	4.383	9.582	12.098	17.296	0.288	-0.560
13	1.212	2.211	2.907	4.462	9.820	12.114	17.889	0.313	-0.490
14	1.212	2.212	2.915	4.517	10.102	12.201	18.023	0.338	-0.420
15	1.215	2.231	2.948	4.520	10.497	12.595	18.361	0.363	-0.352
16	1.218	2.261	2.990	4.659	10.508	12.865	18.717	0.388	-0.285
17	1.218	2.275	2.990	4.709	10.680	12.906	18.948	0.413	-0.221
18	1.221	2.281	3.055	4.738	10.958	13.284	19.146	0.438	-0.157
19	1.225	2.294	3.067	4.778	11.124	13.480	19.237	0.463	-0.094
20	1.229	2.308	3.071	4.791	11.474	13.599	19.257	0.488	-0.031
21	1.229	2.315	3.099	4.802	11.577	13.738	19.326	0.513	0.031
22	1.229	2.324	3.116	4.959	11.622	14.566	19.651	0.538	0.095
23	1.229	2.345	3.147	4.988	11.664	14.979	19.818	0.563	0.157
24	1.234	2.349	3.172	5.171	11.734	15.188	20.232	0.588	0.220
25	1.234	2.359	3.246	5.248	11.864	15.535	20.542	0.613	0.285
26	1.240	2.373	3.256	5.351	11.944	15.668	20.606	0.638	0.351
27	1.240	2.404	3.363	5.405	11.956	15.949	20.701	0.663	0.420
28	1.246	2.415	3.390	5.441	12.015	15.952	21.005	0.688	0.490
29	1.254	2.438	3.479	5.523	12.299	16.784	21.236	0.713	0.560
30	1.254	2.443	3.511	5.584	12.506	17.178	21.655	0.738	0.635
31	1.263	2.475	3.512	5.638	12.545	17.392	21.798	0.763	0.715
32	1.286	2.518	3.525	5.661	12.571	17.440	21.962	0.788	0.798
33	1.323	2.594	3.531	5.695	12.717	17.634	22.204	0.813	0.888
34	1.351	2.623	3.546	5.856	12.808	18.029	22.418	0.838	0.985
35	1.351	2.642	3.620	5.856	12.885	18.122	23.044	0.863	1.091
36	1.391	2.655	3.734	5.926	13.539	18.494	23.240	0.888	1.215
37	1.391	2.660	3.735	6.171	13.644	18.722	23.699	0.913	1.355
38	1.449	2.703	3.842	6.198	13.775	19.075	25.355	0.938	1.535
39	1.547	2.711	3.871	6.531	13.821	19.479	25.502	0.963	1.780
40	1.547	2.715	3.949	6.890	13.948	19.776	25.855	0.988	2.241

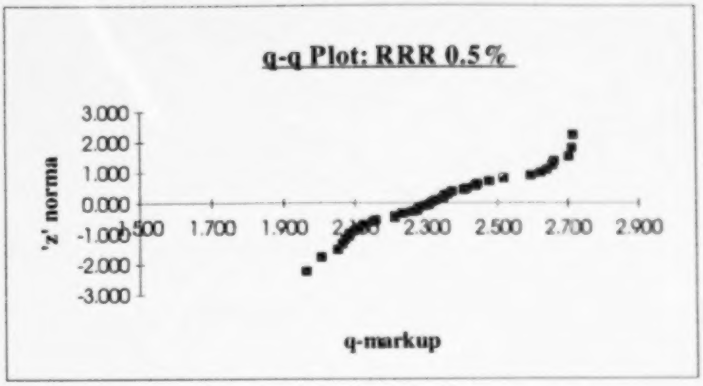

Figure B-2: Q-Q plot for simulation of RRR = 0.5%

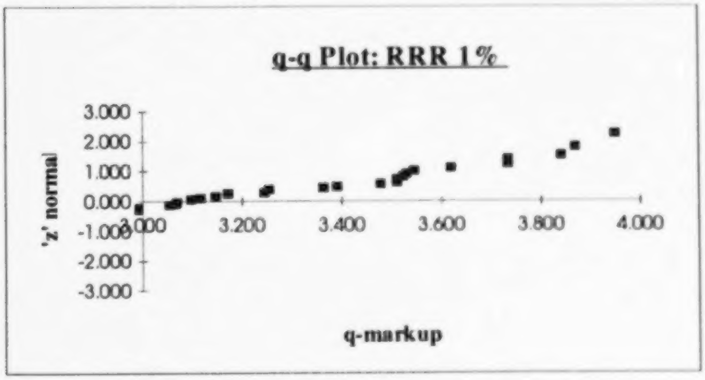

Figure B-3: Q-Q plot for simulation of RRR = 1%

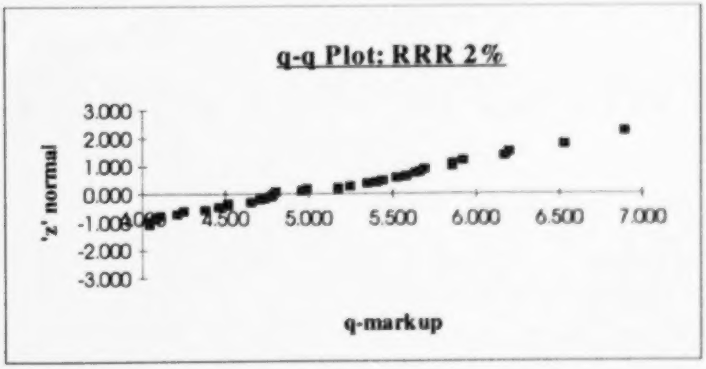

Figure B-4: Q-Q plot for simulation of RRR = 2%

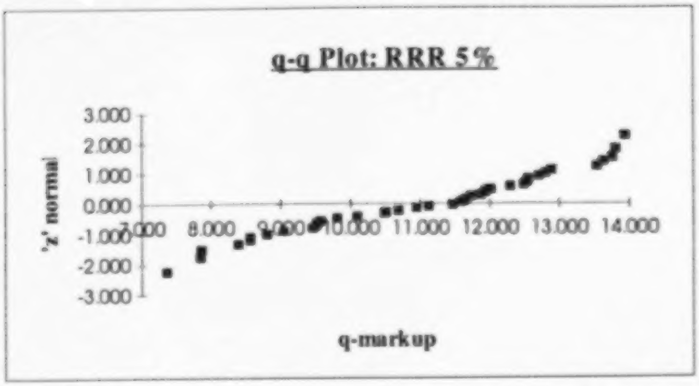

Figure B-5: Q-Q plot for simulation of RRR = 5%

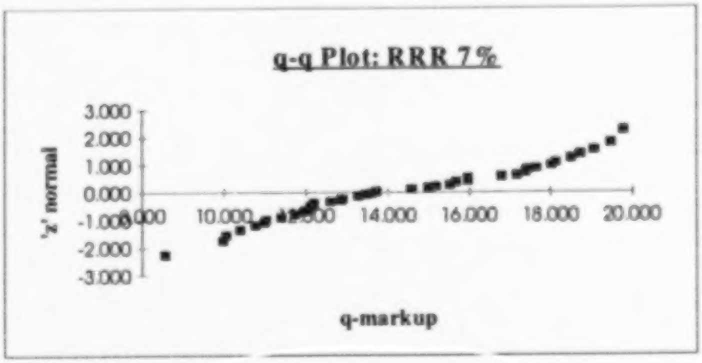

Figure B-6: Q-Q plot for simulation of RRR = 7%

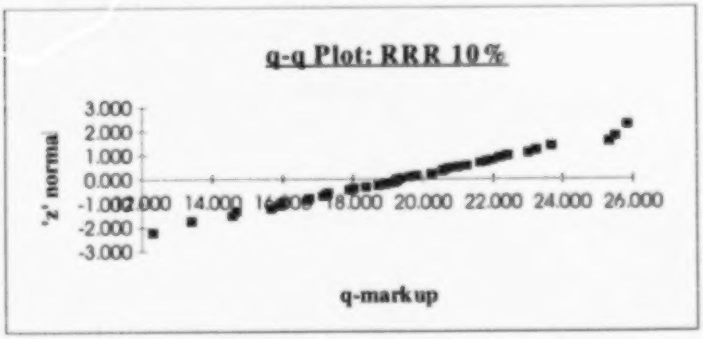

Figure B-7: Q-Q plot for simulation of RRR = 10%

Table B-3: Monte Carlo simulation of 40 runs for RRR = 0%

```
Run     Project Cost     Duration        RRR (%)         Markup(%)
***     ************     ********     *************      *********
 1       $14295342          23             0.0             1.207
 2        $7802361          15             0.0             1.234
 3        $2369997          23             0.0             1.207
 4       $15442911          24             0.0             1.205
 5       $10442739          23             0.0             1.207
 6       $19299418          12             0.0             1.254
 7        $9402807           9             0.0             1.286
 8       $16027363          16             0.0             1.229
 9        $6874793           7             0.0             1.323
10        $9594964           5             0.0             1.391
11       $16634452          14             0.0             1.240
12        $1561470          21             0.0             1.212
13        $3505682          11             0.0             1.263
14        $3745717           5             0.0             1.391
15        $4449861           4             0.0             1.449
16        $2457771          16             0.0             1.229
17       $19778836          22             0.0             1.209
18        $1665853          24             0.0             1.205
19        $7713286          18             0.0             1.221
20       $15145719          25             0.0             1.203
21       $16097876          22             0.0             1.209
22        $3441196           3             0.0             1.547
23       $19026165          23             0.0             1.207
24        $4137361          22             0.0             1.209
25       $16186301          17             0.0             1.225
26        $5329553          14             0.0             1.240
27       $10384930          16             0.0             1.229
28       $12857088          15             0.0             1.234
29       $12817191          20             0.0             1.215
30        $3136676          24             0.0             1.205
31        $9793149          22             0.0             1.209
32       $17409760          21             0.0             1.212
33        $6980478          13             0.0             1.246
34       $10692704           3             0.0             1.547
35        $1292120          19             0.0             1.218
36       $18333254          12             0.0             1.254
37        $9364862          19             0.0             1.218
38       $10596951           6             0.0             1.351
39        $8324930           6             0.0             1.351
40       $15261335          16             0.0             1.229

          Company RRR(%) 0.0
          Payment Policy (workdays)20
          Holdback Amount (%)15.0
          Holdback released after completion (days) 45

          Average Markup (%) 1.3
          Standard Deviation of Markups 0.09
          Confidence  (95%) +/- 0.03
```

Table B-4: Monte Carlo simulation of 40 runs for RRR = 0.5%

Run	Project Cost	Duration	RRR (%)	Markup(%)
***	************	********	*************	*********
1	$11925136	25	0.5	2.715
2	$2740648	25	0.5	2.660
3	$15533630	15	0.5	2.324
4	$4428867	13	0.5	2.158
5	$4275956	11	0.5	2.211
6	$8484211	20	0.5	2.438
7	$13156574	10	0.5	2.072
8	$18789075	25	0.5	2.594
9	$12612670	16	0.5	2.359
10	$17997157	9	0.5	2.085
11	$14548903	24	0.5	2.642
12	$13733047	21	0.5	2.415
13	$8931711	15	0.5	2.373
14	$19772500	12	0.5	2.054
15	$11859999	16	0.5	2.212
16	$12532225	24	0.5	2.655
17	$5363765	23	0.5	2.623
18	$13724417	16	0.5	2.275
19	$1347668	10	0.5	2.112
20	$19380856	18	0.5	2.294
21	$6852532	14	0.5	2.281
22	$9076676	15	0.5	2.345
23	$11764930	22	0.5	2.518
24	$15413321	6	0.5	1.962
25	$7252806	13	0.5	2.308
26	$18589623	5	0.5	2.007
27	$13157259	13	0.5	2.315
28	$14637362	20	0.5	2.404
29	$19444726	25	0.5	2.711
30	$8772155	13	0.5	2.231
31	$18404794	11	0.5	2.080
32	$5500100	17	0.5	2.443
33	$4283970	15	0.5	2.349
34	$10660512	24	0.5	2.475
35	$7892463	4	0.5	2.125
36	$12348731	11	0.5	2.098
37	$2700134	7	0.5	2.066
38	$4811264	24	0.5	2.703
39	$17108218	17	0.5	2.261
40	$3523319	12	0.5	2.147

Company RRR(%) 0.5
Payment Policy (workdays)20
Holdback Amount (%)15.0
Holdback released after completion (days) 45

Average Markup (%) 2.3
Standard Deviation of Markups 0.22
Confidence (95%) +/- 0.07

Table B-5: Monte Carlo simulation of 40 runs for RRR = 1%

```
Run    Project Cost    Duration         RRR (%)        Markup(%)
***    ************    ********      *************     *********
 1          $817188       17              1.0            3.390
 2        $18106334        8              1.0            2.735
 3        $10689861        9              1.0            3.071
 4        $10185854       10              1.0            3.055
 5         $3201572       24              1.0            3.735
 6        $10074141        5              1.0            2.907
 7         $6129860       24              1.0            3.949
 8         $1048592        7              1.0            2.643
 9        $17377601       20              1.0            3.546
10        $10177224        4              1.0            2.458
11         $1768695       13              1.0            3.246
12         $4240853       13              1.0            3.067
13        $15793766       12              1.0            3.363
14         $2456880        5              1.0            2.905
15         $1176914       20              1.0            3.871
16         $5137154        8              1.0            2.990
17        $16194040       11              1.0            2.990
18        $19906266       23              1.0            3.734
19         $4440339       10              1.0            3.099
20         $9888662       10              1.0            2.948
21        $16793149        6              1.0            2.875
22        $18025239       15              1.0            3.116
23         $7816778        9              1.0            2.739
24        $14753183       19              1.0            3.620
25        $13225203       13              1.0            3.147
26        $11977155       19              1.0            3.511
27         $3455613       20              1.0            3.479
28        $15536471        7              1.0            2.836
29         $9856093       17              1.0            3.525
30         $6127908       19              1.0            3.512
31         $2863832        4              1.0            2.654
32         $4839962        8              1.0            2.820
33         $2319928        9              1.0            2.844
34         $4048044       15              1.0            3.256
35         $4256161       18              1.0            3.531
36         $7720374       10              1.0            2.784
37         $2747393        5              1.0            2.915
38         $1995373        7              1.0            2.838
39        $13612121       12              1.0            3.172
40         $2691537       25              1.0            3.842

       Company RRR(%) 1.0
       Payment Policy (workdays)20
       Holdback Amount (%)15.0
       Holdback released after completion (days) 45

       Average Markup (%) 3.2
       Standard Deviation of Markups 0.38
       Confidence  (95%) +/- 0.12
```

Table B-6: Monte Carlo simulation of 40 runs for RRR = 2%

```
Run    Project Cost     Duration       RRR (%)        Markup(%)
***    ************     ********    *************     *********
 1        $17976232        20            2.0             6.171
 2         $8507086        12            2.0             4.738
 3         $4066777        12            2.0             4.988
 4         $2570715        21            2.0             5.856
 5        $14435478        23            2.0             6.198
 6          $786742        13            2.0             4.778
 7        $15067806        13            2.0             5.171
 8        $15059827        10            2.0             4.802
 9        $18492122        10            2.0             4.517
10         $6643319        15            2.0             5.248
11         $6738421        10            2.0             4.383
12         $8218524        18            2.0             5.695
13        $11154792        22            2.0             5.926
14         $8418661        17            2.0             5.661
15        $10114860         8            2.0             4.115
16        $13083046         4            2.0             3.920
17        $15523286        13            2.0             5.405
18        $18243458        10            2.0             4.462
19        $11819039         3            2.0             4.044
20        $11995237        15            2.0             4.659
21        $10283080        16            2.0             5.523
22         $4457770         4            2.0             3.931
23        $13098354        10            2.0             4.791
24        $19042704         5            2.0             4.252
25        $12554450        15            2.0             5.584
26        $18250786        12            2.0             4.959
27         $2897873         7            2.0             4.217
28         $2393866         7            2.0             3.916
29        $19218903        17            2.0             5.856
30         $6562223        21            2.0             6.531
31         $8145408         5            2.0             3.813
32         $9129483        16            2.0             5.441
33         $9585614        18            2.0             5.351
34        $10321675         8            2.0             3.823
35        $13505957        11            2.0             4.520
36        $15978115        10            2.0             4.709
37        $12281847         5            2.0             4.088
38        $14194142        25            2.0             6.890
39        $12914176        17            2.0             5.638
40        $16874416         5            2.0             4.046

        Company RRR(%) 2.0
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 5.0
        Standard Deviation of Markups 0.82
        Confidence  (95%) +/- 0.26
```

Table B-7: Monte Carlo simulation of 40 runs for RRR = 5%

```
Run   Project Cost     Duration      RRR (%)       Markup(%)
***   ************     ********   *************    *********
 1      $16635888         22           5.0           13.821
 2        $818865         12           5.0           10.497
 3      $14603902         16           5.0           11.577
 4        $522975         15           5.0           11.622
 5      $19020272          5           5.0            7.357
 6        $723112         14           5.0           10.958
 7       $8258627         20           5.0           12.885
 8      $18851402         18           5.0           11.944
 9      $13667052         24           5.0           13.775
10      $16075375         18           5.0           12.808
11      $17275546         13           5.0           12.015
12      $17763594          6           5.0            8.804
13      $12083216         16           5.0           11.734
14      $19947841         13           5.0            9.514
15      $14898491          9           5.0            9.820
16      $16874621         13           5.0           11.956
17       $2761776         20           5.0           12.571
18      $16082703         20           5.0           12.545
19       $8354380         17           5.0           11.864
20       $3882153          3           5.0            8.383
21      $16738971         21           5.0           13.539
22      $15986950         23           5.0           13.644
23      $11730819         15           5.0           12.299
24      $10446127         12           5.0            9.540
25       $3277667         11           5.0           10.102
26      $11638319          4           5.0            7.874
27      $18790820         21           5.0           12.717
28      $17294758          6           5.0            7.842
29       $9630271          9           5.0            9.582
30      $11854415         10           5.0           10.508
31       $6606229         11           5.0            9.471
32       $6598250          7           5.0            8.568
33      $11901641          7           5.0            8.562
34      $19582087         12           5.0           10.680
35      $14149724         20           5.0           12.506
36      $19286197         15           5.0           11.124
37       $2693215         20           5.0           11.664
38       $7893524         21           5.0           11.474
39       $1653283          6           5.0            9.055
40       $4621468         25           5.0           13.948

        Company RRR(%) 5.0
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%)11.0
        Standard Deviation of Markups 1.85
        Confidence  (95%) +/- 0.59
```

Table B-8: Monte Carlo simulation of 40 runs for RRR = 7%

```
Run    Project Cost      Duration         RRR (%)         Markup(%)
***    ************      ********     *************       *********
 1       $14843490          16              7.0              14.566
 2        $1690782          24              7.0              17.634
 3        $8558626          11              7.0              12.906
 4       $13014894          18              7.0              16.784
 5       $14959107           7              7.0              12.201
 6       $15199141          25              7.0              17.392
 7       $15903285          24              7.0              17.178
 8       $17567566          24              7.0              19.075
 9       $19015751          17              7.0              15.188
10       $16775648           8              7.0              12.595
11       $11230270           8              7.0              12.865
12       $18662703          15              7.0              15.952
13       $11678421           6              7.0              11.982
14       $14894620          23              7.0              18.722
15        $6670270          24              7.0              18.029
16       $19247155           6              7.0              10.780
17        $8110475          13              7.0              14.979
18        $8846537           4              7.0              10.043
19       $12030818           6              7.0              10.982
20       $14502976           6              7.0              10.393
21       $10806709          23              7.0              19.479
22       $10933729          10              7.0              11.728
23       $17590203           8              7.0              11.987
24        $5677564           7              7.0              12.098
25        $1485269           5              7.0               9.966
26       $16790306          12              7.0              13.738
27       $18982532          22              7.0              18.494
28        $8557975           9              7.0              12.114
29        $3869653          11              7.0              13.284
30        $5101742          21              7.0              18.122
31       $12637257           3              7.0               8.560
32       $11637222           8              7.0              11.422
33       $10109243          24              7.0              17.440
34        $8861195           8              7.0              11.025
35       $17997806           9              7.0              13.599
36       $18485854          25              7.0              19.776
37       $16461847          22              7.0              15.668
38        $4797221          19              7.0              15.969
39       $11169038           9              7.0              13.480
40       $13145168          13              7.0              15.535

         Company RRR(%) 7.0
         Payment Policy (workdays)20
         Holdback Amount (%)15.0
         Holdback released after completion (days) 45

         Average Markup (%)14.3
         Standard Deviation of Markups 3.07
         Confidence  (95%) +/- 0.98
```

Table B-9: Monte Carlo simulation of 40 runs for RRR = 10%

```
Run    Project Cost    Duration      RRR (%)       Markup(%)
***    ************    ********   *************    *********
 1       $17743285        17          10.0           19.818
 2        $3598522        11          10.0           18.361
 3        $6879242        13          10.0           15.956
 4       $10343455         5          10.0           14.586
 5        $3671022        23          10.0           25.502
 6       $14511811        19          10.0           23.699
 7       $18192120        17          10.0           21.236
 8       $15207976        14          10.0           21.798
 9       $11695886        24          10.0           25.855
10         $527288        17          10.0           23.240
11       $15616229        17          10.0           19.257
12        $8054824        19          10.0           21.005
13       $11983147        15          10.0           19.237
14       $14207291        17          10.0           20.606
15        $8959105        17          10.0           22.418
16        $1014686         8          10.0           17.143
17       $12383421        14          10.0           19.651
18       $12127427        13          10.0           19.326
19         $629720        14          10.0           18.717
20       $13702633        16          10.0           20.701
21        $5046091         3          10.0           14.658
22       $10246400         4          10.0           15.692
23        $4006159        12          10.0           17.889
24        $6974344         8          10.0           16.741
25       $17351024        23          10.0           21.962
26        $4198316         8          10.0           16.731
27        $1430268        12          10.0           17.293
28        $5886536        19          10.0           22.204
29       $17638285        14          10.0           19.146
30       $17878319         9          10.0           18.023
31       $18582463         8          10.0           17.296
32       $16590373        20          10.0           21.655
33       $18038559        13          10.0           20.232
34       $15798455         4          10.0           15.975
35        $8381982         5          10.0           13.417
36       $19470785        22          10.0           25.355
37        $8830132        25          10.0           23.044
38        $4109892        13          10.0           18.948
39       $13457873         3          10.0           12.343
40       $14441948        15          10.0           20.542

         Company RRR(%)10.0
         Payment Policy (workdays)20
         Holdback Amount (%)15.0
         Holdback released after completion (days) 45

         Average Markup (%)19.4
         Standard Deviation of Markups 3.24
         Confidence  (95%) +/- 1.04
```

Appendix C: Sensitivity to Amount of Project HoldBack (Retainage)

Monte Carlo Study for Sensitivity Analysis of Cash Flow Model to Amount of Project Holdback

The amount of project holdback is varied from 0% to 30% of the all invoices for the project with the recommended markup determined by the cash flow analysis model. The values for other variables which are held constant are shown below. The monte carlo study is simulated for 40 runs randomly generating project duration, total cost and cost distribution for each run. The results of the 40 run simulation are provided in Tables C-3 to C-9 with the average markup, standard deviation and 95% confidence interval calculated for each table. A summary of the Monte Carlo study is shown in Table C-1.

External Variables:

Payment Policy =	20 wk dys
RRR =	2.5% per month
Holdback =	variable
Billing Factor =	1.0

Payroll Burden is 24% of labour amount

Table C-1: Summary of Monte Carlo study for holdback amount

Holdback (%)	Average Markup (%)	Confidence Interval	Upper Limit	Lower Limit
0	3.6	0.08	3.68	3.52
5	4.5	0.12	4.62	4.38
10	5.2	0.24	5.44	4.96
15	6.0	0.36	6.36	5.64
20	6.9	0.54	7.44	6.36
25	7.9	0.64	8.54	7.26
30	8.8	0.74	9.54	8.06

The quantile quantile (q-q) plot is produces for each 40 run simulation to check for normality. If the plot presents a linear pattern the accuracy of the 95% confidence interval is proved. The data for the q-q plots is contained in Table C-2 with the plots shown in Figures C-1 to C-7.

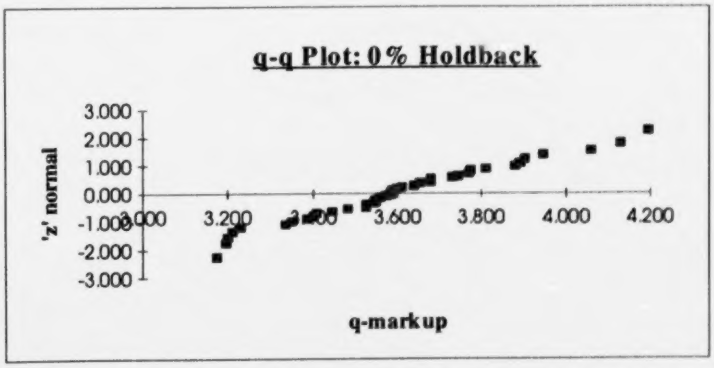

Figure C-1: Q-Q plot for simulation of holdback amount = 0%

Table C-2: Data for quantile-quantile plots for holdback analysis

	Holdback Amounts (X)								
#	0%	5%	10%	15%	20%	25%	30%	Phi	'z' (Y)
1	3.175	3.722	3.887	4.106	4.164	4.644	4.949	0.013	-2.240
2	3.197	3.839	4.114	4.247	4.381	4.759	5.069	0.038	-1.780
3	3.200	3.904	4.188	4.345	4.453	4.992	5.234	0.063	-1.535
4	3.211	3.922	4.340	4.363	4.480	5.314	5.587	0.088	-1.355
5	3.230	3.923	4.363	4.637	4.552	5.711	5.779	0.113	-1.213
6	3.336	3.947	4.487	4.737	4.852	5.825	5.953	0.138	-1.092
7	3.352	4.019	4.525	5.006	4.927	5.840	6.011	0.163	-0.985
8	3.386	4.038	4.551	5.006	4.935	5.989	6.326	0.188	-0.888
9	3.401	4.041	4.576	5.061	5.225	5.991	6.523	0.213	-0.798
10	3.409	4.060	4.674	5.114	5.490	6.106	6.530	0.238	-0.715
11	3.444	4.068	4.685	5.182	5.496	6.119	6.531	0.263	-0.635
12	3.484	4.110	4.693	5.183	5.516	6.146	7.392	0.288	-0.560
13	3.526	4.125	4.704	5.188	5.698	6.190	7.647	0.313	-0.490
14	3.527	4.148	4.723	5.193	6.229	6.200	7.657	0.338	-0.420
15	3.544	4.252	4.832	5.257	6.284	6.422	7.914	0.363	-0.352
16	3.547	4.414	4.857	5.357	6.361	6.833	8.215	0.388	-0.285
17	3.548	4.416	4.910	5.361	6.705	6.975	8.300	0.413	-0.221
18	3.559	4.468	4.960	5.396	6.965	7.253	8.311	0.438	-0.157
19	3.572	4.490	5.000	5.453	7.073	7.659	8.382	0.463	-0.094
20	3.585	4.514	5.003	5.766	7.245	7.894	8.884	0.488	-0.031
21	3.585	4.527	5.008	5.898	7.369	7.978	9.023	0.513	0.031
22	3.590	4.599	5.020	5.901	7.425	8.278	9.052	0.538	0.095
23	3.601	4.615	5.106	5.907	7.430	8.366	9.129	0.563	0.157
24	3.610	4.623	5.394	5.995	7.485	8.424	9.589	0.588	0.220
25	3.638	4.664	5.515	6.409	7.505	8.604	10.301	0.613	0.285
26	3.654	4.666	5.519	6.644	7.647	9.097	10.321	0.638	0.351
27	3.678	4.673	5.546	6.712	7.738	9.391	10.387	0.663	0.420
28	3.679	4.702	5.704	6.718	7.861	9.413	10.401	0.688	0.490
29	3.731	4.720	5.772	6.772	7.926	9.478	10.545	0.713	0.560
30	3.744	4.758	5.912	6.878	7.937	9.576	10.558	0.738	0.635
31	3.771	4.823	5.913	6.924	8.067	9.601	10.746	0.763	0.715
32	3.774	4.862	5.988	7.003	8.134	9.650	10.888	0.788	0.798
33	3.812	4.864	6.073	7.111	8.352	9.727	10.979	0.813	0.888
34	3.880	4.909	6.157	7.156	8.866	9.868	11.165	0.838	0.985
35	3.893	4.924	6.192	7.401	8.936	9.937	11.483	0.863	1.091
36	3.902	4.940	6.195	7.663	9.302	10.030	11.909	0.888	1.215
37	3.947	4.953	6.255	7.681	9.422	10.939	11.968	0.913	1.355
38	4.059	4.959	6.484	7.839	9.450	11.092	12.103	0.938	1.535
39	4.130	4.968	6.757	7.850	9.991	11.149	12.823	0.963	1.780
40	4.197	5.032	6.783	8.095	9.996	11.998	12.841	0.988	2.241

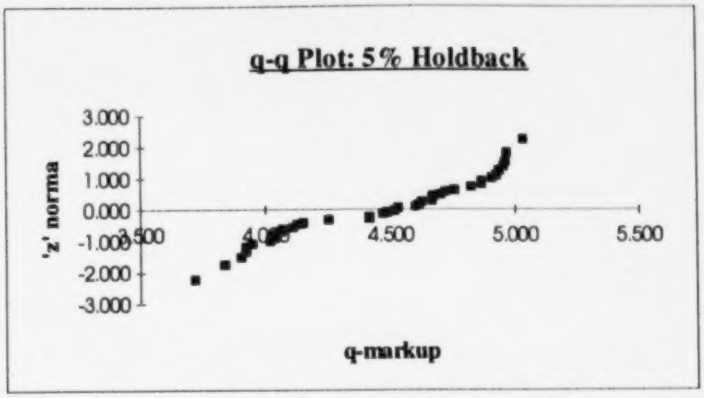

Figure C-2: Q-Q plot for simulation of holdback amount = 5%

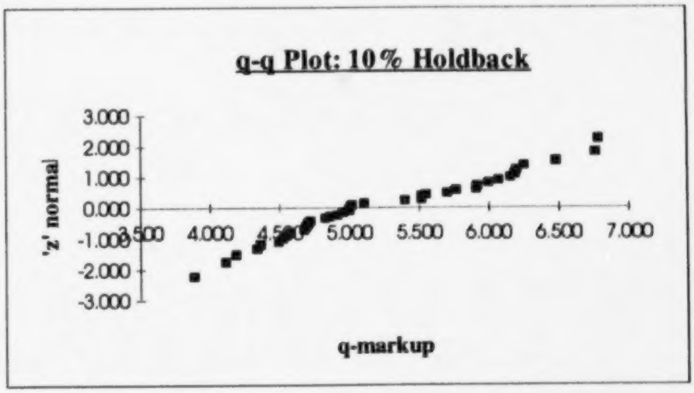

Figure C-3: Q-Q plot for simulation of holdback amoutn = 10%

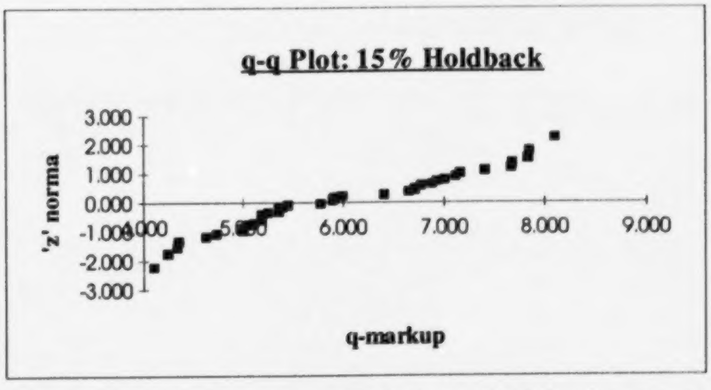

Figure C-4: Q-Q plot for simulation of holdback amount = 15%

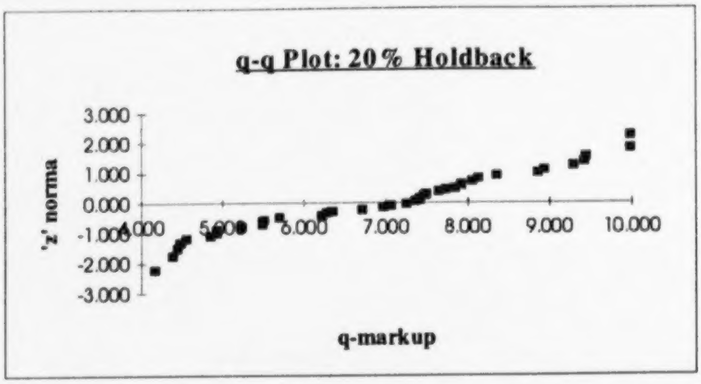

Figure C-5: Q-Q plot for simulation of holdback amount = 20%

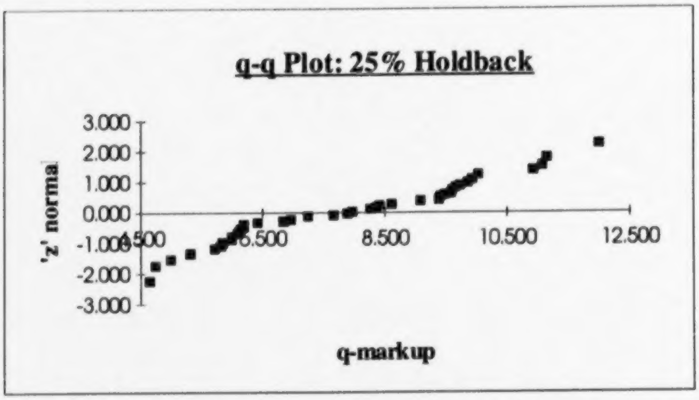

Figure C-6: Q-Q plot for simulation of holdback amount = 25%

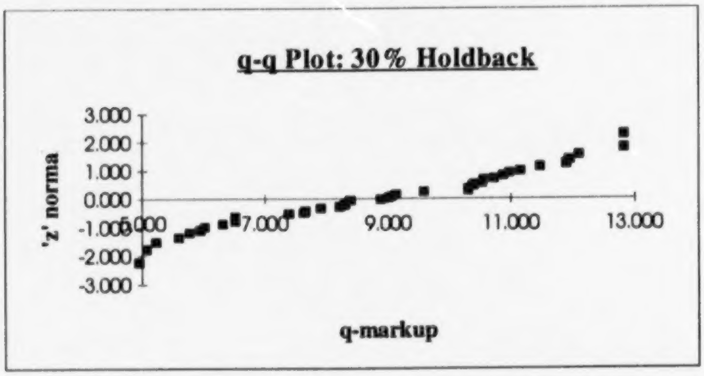

Figure C-7: Q-Q plot for simulation of holdback amount = 30%

Table C-3: Monte Carlo simulation of 40 runs for holdback amount = 0%

```
Run    Project Cost     Duration    Holdback(%)     Markup(%)
***    ************     ********    ************    *********
 1          $1624468        8           0.0            3.200
 2          $9304915       13           0.0            3.679
 3         $19121732        3           0.0            4.197
 4          $1072585       10           0.0            3.527
 5         $11945292       21           0.0            3.744
 6          $1272722       10           0.0            3.386
 7         $14561731       18           0.0            3.572
 8         $17529916       14           0.0            3.774
 9          $2312003       22           0.0            3.880
10         $12968614        3           0.0            4.130
11          $6544195       18           0.0            3.409
12         $11000463       25           0.0            3.585
13          $5008236        9           0.0            3.175
14          $8904641       14           0.0            3.548
15          $5952414       25           0.0            3.654
16          $7616696       25           0.0            3.401
17         $10764333       18           0.0            3.601
18         $12180601       20           0.0            3.544
19          $4764127       21           0.0            3.585
20         $15852930       15           0.0            3.336
21          $8868648        6           0.0            4.059
22         $12084847       23           0.0            3.352
23          $8140566       19           0.0            3.731
24         $17061081       14           0.0            3.230
25         $19388307       14           0.0            3.559
26           $595119        5           0.0            3.678
27         $15372211       24           0.0            3.484
28          $1971489       12           0.0            3.197
29         $17804471        6           0.0            3.444
30          $4467585       22           0.0            3.547
31          $6843990       25           0.0            3.590
32          $4738887        7           0.0            3.902
33           $546592        5           0.0            3.610
34         $19507999       22           0.0            3.947
35         $18043855       22           0.0            3.812
36         $19212109        3           0.0            3.526
37         $14523786        5           0.0            3.638
38          $4163065       21           0.0            3.893
39         $17763923       10           0.0            3.771
40           $891009       25           0.0            3.211

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%) 0.0
        Holdback released after completion (days) 45

        Average Markup (%) 3.6
        Standard Deviation of Markups 0.25
        Confidence  (95%) +/- 0.08
```

Table C-4: Monte Carlo simulation of 40 runs for holdback amount = 5%

```
Run      Project Cost     Duration    Holdback(%)     Markup(%)
***      ************     ********   *************    *********
 1          $2350220         21           5.0           5.032
 2          $8726763          6           5.0           4.490
 3          $2302344         22           5.0           4.664
 4          $2478542         11           5.0           4.623
 5          $8702824         19           5.0           4.924
 6          $8942859         13           5.0           4.110
 7         $11518099         12           5.0           4.599
 8         $17462449          7           5.0           4.041
 9         $10974195         17           5.0           4.959
10         $16670531         14           5.0           4.527
11          $4973988         20           5.0           4.862
12          $8126352          8           5.0           4.514
13          $5422139         17           5.0           4.673
14          $2572994          5           5.0           3.722
15         $10221523         18           5.0           4.702
16         $11205599          6           5.0           4.252
17         $11661729          7           5.0           4.060
18         $12397791         21           5.0           4.758
19         $11925702         13           5.0           4.038
20         $14397859         12           5.0           4.615
21         $14357962         17           5.0           4.968
22         $12613887          5           5.0           4.019
23         $11333921         20           5.0           4.940
24         $15294161          7           5.0           4.148
25         $16457689         16           5.0           4.823
26           $640665          6           5.0           4.125
27          $6489262          4           5.0           3.922
28         $11937585          3           5.0           3.947
29          $7249262          5           5.0           3.923
30          $8481352         15           5.0           4.720
31          $6209331         15           5.0           4.953
32          $5209296         19           5.0           4.468
33          $3681317         13           5.0           3.839
34          $2433268         19           5.0           4.416
35         $13440976         20           5.0           4.864
36          $2336214         19           5.0           4.909
37         $19841456         16           5.0           3.904
38          $4520461         25           5.0           4.666
39          $1256385         10           5.0           4.068
40          $3232515         14           5.0           4.414

         Company RRR(%) 2.5
         Payment Policy (workdays)20
         Holdback Amount (%) 5.0
         Holdback released after completion (days) 45

         Average Markup (%) 4.5
         Standard Deviation of Markups 0.39
         Confidence  (95%) +/- 0.12
```

Table C-5: Monte Carlo simulation of 40 runs for holdback amount = 10%

```
Run   Project Cost     Duration     Holdback(%)      Markup(%)
***   ************     ********    **************    *********
 1       $7346934          7           10.0            4.363
 2      $11059161         20           10.0            6.157
 3       $5314948         24           10.0            6.783
 4      $10763270         23           10.0            5.772
 5       $9731318         13           10.0            5.020
 6      $14619778         10           10.0            4.340
 7        $754947         16           10.0            5.519
 8      $13218819         14           10.0            5.000
 9       $8034469         20           10.0            6.192
10      $10442791         14           10.0            4.910
11      $11642962          9           10.0            5.003
12      $12131010         25           10.0            6.484
13      $14387072         18           10.0            5.913
14      $10658887         21           10.0            5.988
15       $7394811          5           10.0            4.487
16       $9370941          9           10.0            4.857
17      $16486799         16           10.0            5.515
18      $18214916         22           10.0            6.255
19      $18423032         25           10.0            6.757
20      $17607176         22           10.0            6.195
21      $14591114          4           10.0            4.576
22      $13839093          7           10.0            4.674
23       $5926592         11           10.0            4.704
24       $4813543          8           10.0            4.693
25      $17174333          7           10.0            4.114
26      $13942175          6           10.0            4.551
27      $13158237         17           10.0            5.394
28      $19598614          8           10.0            4.188
29      $19870567         17           10.0            5.704
30       $2565461         18           10.0            4.960
31      $16846525         19           10.0            5.912
32        $965666          3           10.0            3.887
33      $12334401         10           10.0            5.106
34      $20014847         14           10.0            4.723
35        $580700          9           10.0            4.832
36       $2060803         17           10.0            5.008
37      $16589881         15           10.0            5.546
38      $13853750         10           10.0            4.525
39      $15549949         25           10.0            6.073
40       $2645255          8           10.0            4.685

      Company RRR(%) 2.5
      Payment Policy (workdays)20
      Holdback Amount (%)10.0
      Holdback released after completion (days) 45

      Average Markup (%) 5.2
      Standard Deviation of Markups 0.77
      Confidence  (95%) +/- 0.24
```

Table C-6: Monte Carlo simulation of 40 runs for holdback amount = 15%

```
Run   Project Cost    Duration    Holdback(%)    Markup(%)
***   ************    ********   *************   *********
 1        $9405086       16          15.0          6.878
 2       $19749848       16          15.0          6.718
 3        $3120222       11          15.0          5.901
 4        $3608270        4          15.0          4.247
 5       $17457142       14          15.0          5.907
 6       $10072586        6          15.0          5.188
 7        $3152140        3          15.0          4.737
 8        $5128270        6          15.0          5.193
 9        $2608236        8          15.0          5.357
10        $4336352       14          15.0          5.995
11       $12480909       23          15.0          7.850
12       $19601492        3          15.0          4.106
13       $12929059       20          15.0          7.401
14       $15833409       10          15.0          5.183
15        $1855564        9          15.0          5.114
16       $18400670        6          15.0          4.345
17       $11232210        4          15.0          4.637
18       $15936491        9          15.0          5.006
19       $15152553       20          15.0          7.111
20       $13656491        6          15.0          5.061
21        $9648374       19          15.0          7.003
22       $11872518       21          15.0          7.663
23        $6624332       21          15.0          8.095
24        $2959982        7          15.0          5.257
25       $14328717       13          15.0          5.898
26        $8007380        5          15.0          5.182
27        $2575016       13          15.0          5.766
28        $7711490        9          15.0          5.453
29       $18584197       19          15.0          6.772
30        $7911627        8          15.0          5.361
31       $17544266        6          15.0          5.396
32         $983201       24          15.0          7.839
33        $7079812       21          15.0          7.681
34        $3734640       12          15.0          6.409
35       $16839471        5          15.0          4.363
36        $5422859       23          15.0          6.924
37       $15303512       18          15.0          6.644
38       $19199917       23          15.0          7.156
39        $4654880       18          15.0          6.712
40        $2662790        7          15.0          5.006

         Company RRR(%) 2.5
         Payment Policy (workdays)20
         Holdback Amount (%)15.0
         Holdback released after completion (days) 45

         Average Markup (%) 6.0
         Standard Deviation of Markups 1.13
         Confidence  (95%) +/- 0.36
```

Table C-7: Monte Carlo simulation of 40 runs for holdback amount = 20%

```
Run     Project Cost      Duration     Holdback(%)      Markup(%)
***     ************      ********     *************    *********
 1          $6341181         24            20.0           9.450
 2         $14701833         17            20.0           7.430
 3         $10261524         17            20.0           7.738
 4          $2700119         19            20.0           8.866
 5         $10284812          3            20.0           4.381
 6         $12508956          5            20.0           4.852
 7         $11540839         24            20.0           9.422
 8         $15189230          8            20.0           5.490
 9          $7028715         15            20.0           6.965
10         $10429093         24            20.0           9.991
11         $18460635         25            20.0           8.936
12          $8347928         16            20.0           7.425
13         $19220635          4            20.0           4.552
14          $8548065         15            20.0           7.485
15         $18180703         13            20.0           7.369
16          $5276009         19            20.0           8.067
17          $4059879         17            20.0           7.245
18          $2499982         20            20.0           7.937
19          $9367825          6            20.0           5.516
20         $13824093         13            20.0           6.705
21          $4175496          8            20.0           5.496
22          $8071900         14            20.0           6.361
23         $16712484         19            20.0           8.134
24          $6783955         25            20.0           9.996
25         $19824950         12            20.0           7.073
26          $5992037          9            20.0           6.284
27         $12039470          4            20.0           4.480
28         $11535463          4            20.0           4.161
29           $894810          7            20.0           5.225
30          $4111009         24            20.0           9.302
31          $8103167          3            20.0           4.927
32          $9087243         15            20.0           7.926
33          $9543373         16            20.0           7.505
34         $13935806         17            20.0           8.352
35          $5527277          3            20.0           4.453
36          $7999435          3            20.0           4.935
37         $11615908         18            20.0           7.647
38         $17808272         12            20.0           6.229
39          $6806592          9            20.0           5.698
40         $10766832         20            20.0           7.861

           Company RRR(%) 2.5
           Payment Policy (workdays)20
           Holdback Amount (%)20.0
           Holdback released after completion (days) 45

           Average Markup (%) 6.9
           Standard Deviation of Markups 1.69
           Confidence  (95%) +/- 0.54
```

Table C-8: Monte Carlo simulation of 40 runs for holdback amount = 25%

```
Run    Project Cost    Duration    Holdback(%)      Markup(%)
***    ************    ********    *************    *********
 1       $16344880        16          25.0            8.424
 2        $6480186         5          25.0            4.759
 3       $18281113        25          25.0           10.030
 4        $5872446         4          25.0            4.644
 5       $18729264        22          25.0            9.650
 6       $11740256        18          25.0            8.366
 7        $3827754        23          25.0            9.478
 8        $4499981         7          25.0            6.200
 9       $16860770         6          25.0            5.825
10        $5692173        22          25.0            9.868
11       $12844674        16          25.0            8.604
12        $3412172        18          25.0            9.727
13        $9211591        14          25.0            8.278
14       $11435735        16          25.0            9.413
15       $10467619        12          25.0            7.253
16       $10459639         8          25.0            5.840
17        $5955494         3          25.0            4.992
18       $13635941         7          25.0            6.190
19        $8203577        15          25.0            7.894
20       $13340051        10          25.0            6.106
21        $4683508        21          25.0            9.937
22       $13540188        10          25.0            6.975
23        $3643576         7          25.0            5.991
24         $546418        20          25.0            9.097
25       $10923098        11          25.0            6.833
26        $9363201        14          25.0            7.978
27        $2938782         7          25.0            5.711
28       $11051420        24          25.0           11.149
29        $1402822        20          25.0            9.576
30        $5299227        25          25.0           10.939
31       $15810907         7          25.0            5.314
32       $13818818        19          25.0            9.391
33       $19547072         8          25.0            5.989
34       $17306969        22          25.0            9.601
35       $13546866        10          25.0            6.119
36        $1450048        17          25.0            7.659
37       $13995016         8          25.0            6.422
38       $17211216        25          25.0           11.092
39        $8986865        25          25.0           11.998
40        $3733953         8          25.0            6.146

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)25.0
        Holdback released after completion (days) 45

        Average Markup (%) 7.9
        Standard Deviation of Markups 2.01
        Confidence  (95%) +/- 0.64
```

Table C-9: Monte Carlo simulation of 40 runs for holdback amount = 30%

```
Run   Project Cost    Duration     Holdback(%)      Markup(%)
***   ************    ********    *************     *********
 1        $4345496       15            30.0            9.129
 2        $5761763       17            30.0           10.545
 3        $2001660        6            30.0            5.953
 4        $9434093       12            30.0            8.215
 5       $18322690       15            30.0            9.589
 6       $15473546        3            30.0            5.069
 7       $11529264       22            30.0           10.558
 8         $920529       17            30.0            9.023
 9        $9313099       24            30.0           12.103
10        $2112721        8            30.0            6.530
11       $16889813        5            30.0            6.011
12       $19361971        4            30.0            4.949
13        $7729263       15            30.0            9.052
14       $17577998       20            30.0           10.321
15        $4705222       18            30.0           11.165
16        $2428475       22            30.0           11.483
17       $13485360       25            30.0           12.841
18        $1324708        3            30.0            5.234
19       $11453374       19            30.0           10.746
20        $1028817        6            30.0            6.531
21        $7933305       25            30.0           11.909
22        $3100050        5            30.0            5.587
23       $16700909       17            30.0           10.888
24       $12044504       11            30.0            7.657
25       $18452964       11            30.0            7.647
26        $9268476       11            30.0            8.300
27       $18405087       12            30.0            8.311
28        $7300325       11            30.0            7.914
29       $16869128       25            30.0           12.823
30        $5204503       22            30.0           11.968
31       $17813306       19            30.0           10.979
32        $5787654       10            30.0            6.523
33        $3267619       12            30.0            8.382
34        $4995736       17            30.0           10.301
35        $5203852       20            30.0           10.387
36         $731625        6            30.0            6.326
37       $17244813       12            30.0            8.884
38        $4899982       20            30.0           10.401
39        $4923921        8            30.0            7.392
40        $1939776        5            30.0            5.779

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)30.0
        Holdback released after completion (days) 45

        Average Markup (%) 8.8
        Standard Deviation of Markups 2.32
        Confidence  (95%) +/- 0.74
```

Appendix D: Sensitivity to Contract Payment Policy

Monte Carlo Study for Sensitivity Analysis of Cash Flow Model to Payment Policy of Project Contract

The contract payment policy is varied from 5 to 50 workdays with the recommended markup determined by the cash flow analysis model. The values for other variables which are held constant are shown below. The monte carlo study is simulated for 40 runs randomly generating project duration, total cost and cost distribution for each run. The results for each 40 run simulation are provided in Tables D-3 to D-9 with the average markup, standard deviation and 95% confidence interval calculated for each table. A summary of the Monte Carlo study is shown in Table D-1.

External Variables:

Payment Policy =	variable
RRR =	2.5
Holdback =	15%
Billing Factor =	1.0

Payroll Burden is 24% of labour amount

Table D-1: Summary of Monte Carlo study for payment policy

Payment Policy(wkdy)	Average Markup (%)	Confidence Interval	Upper Limit	Lower Limit
5	4.4	0.37	4.77	4.03
10	5.2	0.37	5.57	4.83
15	5.5	0.33	5.83	5.17
20	6.0	0.38	6.38	5.62
30	7.1	0.37	7.47	6.73
40	8.4	0.38	8.78	8.02
50	9.1	0.32	9.42	8.78

The quantile quantile (q-q) plot is produces for each 40 run simulation to check for normality. If the plot presents a linear pattern then the accuracy of the 95% confidence interval is proved. The data for the q-q plots is contained in Table D-2 with the plots shown in Figures D-1 to D-7.

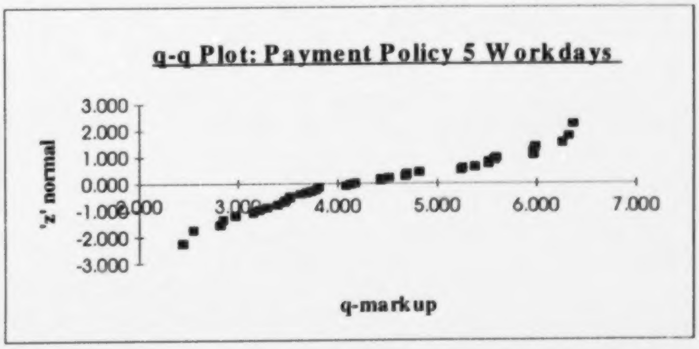

Figure D-1: Q-Q plot for simulation of payment policy = 5 workdays

Table D-2: Data for quantile-quantile plots for payment policy analysis

	Project Payment Policy (Work days), (X)								
#	5	10	15	20	30	40	50	Phi	'z' (Y)
1	2.438	3.216	3.723	3.941	5.332	6.228	7.370	0.013	-2.240
2	2.542	3.567	3.943	4.355	5.343	6.497	7.415	0.038	-1.780
3	2.824	3.725	4.158	4.378	5.428	6.892	7.794	0.063	-1.535
4	2.850	3.727	4.184	4.463	5.530	7.011	7.834	0.088	-1.355
5	2.979	3.834	4.212	4.606	5.872	7.024	7.888	0.113	-1.213
6	3.160	3.927	4.248	4.645	5.916	7.079	7.943	0.138	-1.092
7	3.221	4.024	4.254	4.666	5.934	7.143	8.081	0.163	-0.985
8	3.289	4.097	4.280	4.789	6.019	7.244	8.141	0.188	-0.888
9	3.402	4.176	4.471	4.795	6.138	7.362	8.300	0.213	-0.798
10	3.467	4.283	4.495	4.982	6.169	7.367	8.309	0.238	-0.715
11	3.480	4.294	4.518	5.008	6.197	7.390	8.425	0.263	-0.635
12	3.527	4.350	4.650	5.028	6.286	7.431	8.567	0.288	-0.560
13	3.527	4.495	4.693	5.050	6.332	7.601	8.585	0.313	-0.490
14	3.626	4.569	4.773	5.084	6.382	7.798	8.646	0.338	-0.420
15	3.696	4.570	5.063	5.147	6.433	7.879	8.655	0.363	-0.352
16	3.739	4.577	5.072	5.279	6.494	7.918	8.661	0.388	-0.285
17	3.781	4.613	5.084	5.618	6.537	7.979	8.739	0.413	-0.221
18	3.812	4.745	5.274	5.695	6.727	8.133	8.749	0.438	-0.157
19	4.090	4.833	5.330	5.825	6.825	8.146	8.795	0.463	-0.094
20	4.125	4.899	5.735	5.868	6.835	8.183	8.866	0.488	-0.031
21	4.177	4.955	5.784	5.986	6.997	8.463	9.024	0.513	0.031
22	4.430	4.977	5.833	6.036	7.185	8.516	9.229	0.538	0.095
23	4.438	4.982	5.877	6.061	7.381	8.529	9.590	0.563	0.157
24	4.507	5.109	5.885	6.205	7.440	8.533	9.599	0.588	0.220
25	4.687	5.150	5.917	6.234	7.514	8.559	9.653	0.613	0.285
26	4.688	5.295	5.929	6.463	7.590	9.068	9.707	0.638	0.351
27	4.812	5.592	5.976	6.663	7.812	9.084	9.736	0.663	0.420
28	5.250	5.718	6.042	6.791	7.845	9.098	9.781	0.688	0.490
29	5.262	5.788	6.138	6.855	7.888	9.173	9.821	0.713	0.560
30	5.384	5.874	6.182	7.087	8.012	9.264	9.845	0.738	0.635
31	5.518	6.233	6.191	7.164	8.049	9.434	9.856	0.763	0.715
32	5.519	6.509	6.254	7.318	8.145	9.535	10.014	0.788	0.798
33	5.580	6.576	6.356	7.322	8.151	9.732	10.151	0.813	0.888
34	5.587	6.696	6.486	7.457	8.524	9.834	10.154	0.838	0.985
35	5.970	6.815	6.542	7.512	8.675	9.882	10.213	0.863	1.091
36	5.980	6.863	6.853	7.551	8.887	9.888	10.441	0.888	1.215
37	5.986	6.980	6.914	7.590	8.992	9.977	10.496	0.913	1.355
38	6.263	6.997	7.030	7.796	9.105	10.431	10.655	0.938	1.535
39	6.330	7.240	7.106	7.955	9.126	10.621	10.735	0.963	1.780
40	6.372	7.401	7.759	8.049	9.398	10.883	11.441	0.988	2.241

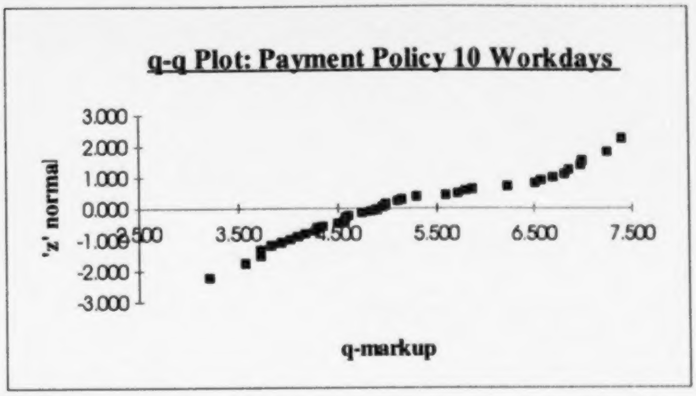

Figure D-2: Q-Q plot for simulation of payment policy =10 workdays

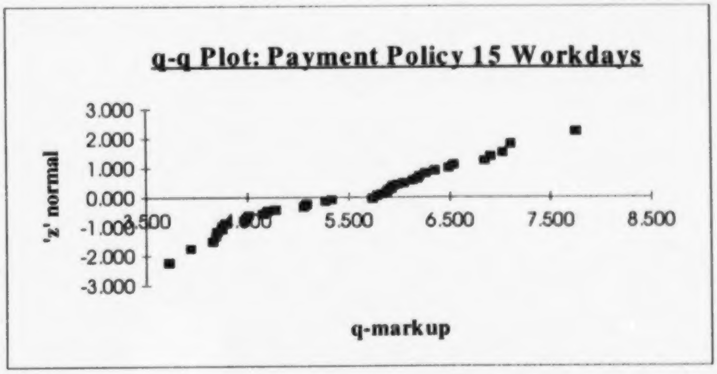

Figure D-3: Q-Q plot for simulation of payment policy =15 workdays

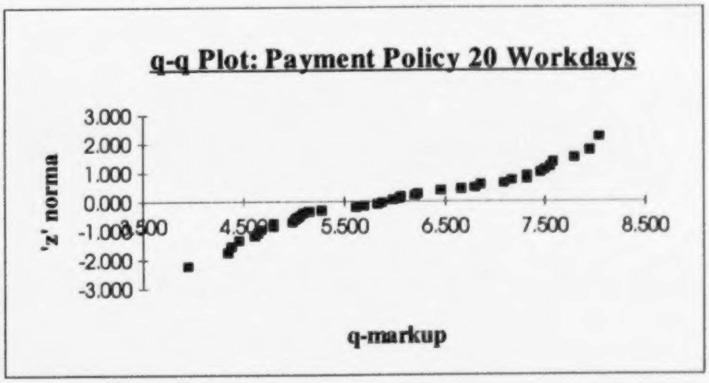

Figure D-4: Q-Q plot for simulation of payment policy =20 workdays

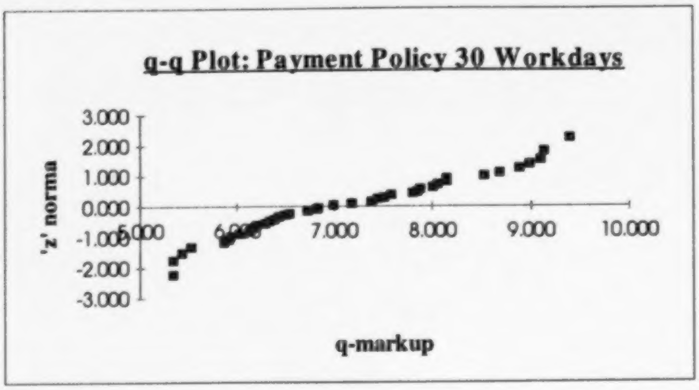

Figure D-5: Q-Q plot for simulation of payment policy =30 workdays

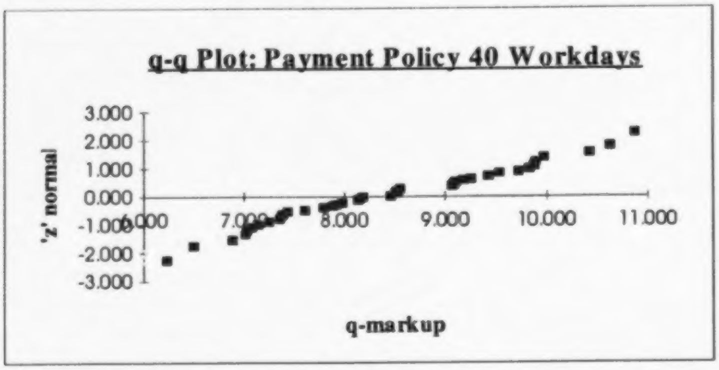

Figure D-6: Q-Q plot for simulation of payment policy =40 workdays

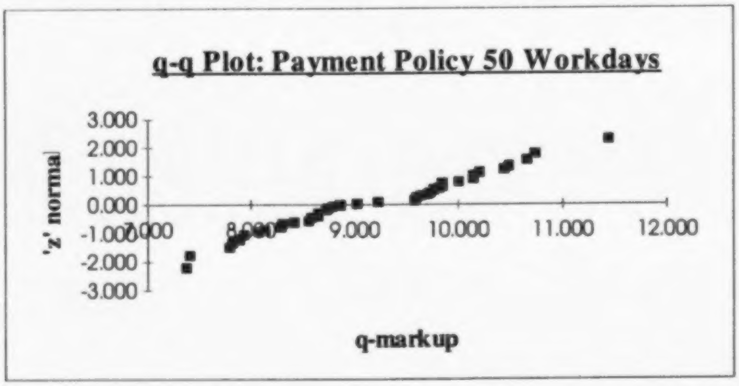

Figure D-7: Q-Q plot for simulation of payment policy =50 workdays

Table D-3: Monte Carlo simulation of 40 runs for payment policy = 5 workdays

```
Run   Project Cost      Duration   Payment(days)   Markup(%)
***   ************      ********   *************   *********
 1      $7783084           22           5.0           6.372
 2     $19119901           14           5.0           4.688
 3     $13687537           22           5.0           6.330
 4     $18240243            6           5.0           3.221
 5      $9583700           17           5.0           5.384
 6     $18440380            6           5.0           3.289
 7      $8543768            3           5.0           2.824
 8     $15168324           10           5.0           4.177
 9      $6015754           24           5.0           6.263
10     $12392296           10           5.0           4.125
11      $5967877            3           5.0           2.542
12     $10424145           10           5.0           3.781
13     $12368358           22           5.0           5.970
14      $6543049           10           5.0           3.527
15      $3590822           21           5.0           5.587
16      $5255103           21           5.0           5.986
17      $6703289           14           5.0           4.438
18      $4463185            6           5.0           3.402
19     $16575962            6           5.0           3.626
20     $16071955            7           5.0           3.467
21      $5431302           10           5.0           3.480
22      $8647501            4           5.0           2.850
23     $10230686           10           5.0           3.527
24     $19151202            5           5.0           2.979
25      $8014522           12           5.0           4.090
26     $12406954           14           5.0           4.430
27      $3998425           22           5.0           5.250
28     $18063393           16           5.0           4.812
29     $18023496           21           5.0           5.580
30      $4686610           14           5.0           4.507
31     $14999454           23           5.0           5.518
32     $12894351            4           5.0           3.160
33      $8702056            3           5.0           2.438
34      $4477843            9           5.0           3.739
35      $3013699            9           5.0           3.696
36     $12118392           19           5.0           4.687
37     $11086440            9           5.0           3.812
38     $12318529           18           5.0           5.519
39     $10046508           18           5.0           5.262
40      $9046474           22           5.0           5.980

            Company RRR(%) 2.5
            Payment Policy (workdays) 5
            Holdback Amount (%)15.0
            Holdback released after completion (days) 45

            Average Markup (%) 4.4
            Standard Deviation of Markups 1.15
            Confidence  (95%) +/- 0.37
```

Table D-4: Monte Carlo simulation of 40 runs for payment policy = 10 workdays

```
Run    Project Cost      Duration    Payment(days)     Markup(%)
***    ************      ********    *************     *********
 1         $4056713         25           10.0            6.233
 2         $2808665          8           10.0            3.927
 3        $11945276          9           10.0            4.577
 4        $16089694         12           10.0            4.982
 5        $10409317         22           10.0            6.696
 6        $18273941         19           10.0            5.788
 7         $5116508         10           10.0            4.745
 8         $7092638         13           10.0            4.955
 9          $916233          4           10.0            3.216
10        $14237160          4           10.0            3.567
11         $2852466         13           10.0            4.977
12         $6316679          5           10.0            4.097
13         $3300617         10           10.0            4.024
14         $2548596         13           10.0            4.350
15         $6228905         11           10.0            4.570
16         $3244761          8           10.0            3.725
17        $15605551          7           10.0            4.294
18         $4436953         23           10.0            6.576
19        $19525894         23           10.0            6.815
20        $11964488         25           10.0            7.240
21        $15892811         21           10.0            5.718
22         $2244076         11           10.0            4.495
23        $12868769         23           10.0            6.980
24         $4924350         14           10.0            5.295
25        $10227741         14           10.0            5.150
26         $9971748         12           10.0            4.899
27        $16132195         14           10.0            5.109
28        $17612298         22           10.0            6.509
29        $12612125         20           10.0            5.592
30         $1939555          9           10.0            4.283
31        $11572194          6           10.0            3.834
32        $14540379         25           10.0            6.863
33         $9044180          4           10.0            3.727
34         $5699008         19           10.0            5.874
35        $18803839         12           10.0            4.569
36        $15323667         13           10.0            4.613
37         $5675069          8           10.0            4.176
38         $9571474         13           10.0            4.833
39         $6619248         25           10.0            6.997
40         $8283529         25           10.0            7.401

          Company RRR(%) 2.5
          Payment Policy (workdays)10
          Holdback Amount (%)15.0
          Holdback released after completion (days) 45

          Average Markup (%) 5.2
          Standard Deviation of Markups 1.15
          Confidence  (95%) +/- 0.37
```

Table D-5: Monte Carlo simulation of 40 runs for payment policy = 15 workdays

```
Run   Project Cost      Duration    Payment(days)    Markup(%)
***   ************      ********    *************    *********
 1        $9085070         14           15.0            5.735
 2        $6844967          5           15.0            4.212
 3       $18957743          6           15.0            4.254
 4       $10517296         23           15.0            7.030
 5       $19405893          3           15.0            3.723
 6        $6749213          8           15.0            4.693
 7        $2804932          4           15.0            3.943
 8        $3789007         16           15.0            5.929
 9        $6116234         16           15.0            6.254
10       $14788735         13           15.0            5.917
11       $17973017         16           15.0            5.833
12         $915924         15           15.0            6.191
13       $12468837         14           15.0            5.784
14        $2788322         18           15.0            6.486
15        $9444796         16           15.0            5.976
16       $17061407         15           15.0            6.138
17       $12869112         13           15.0            6.182
18       $10515995         20           15.0            5.877
19       $12708221          7           15.0            4.184
20       $18156544          6           15.0            4.248
21        $5531781         25           15.0            7.106
22       $10420241         23           15.0            7.759
23        $8148220         22           15.0            6.542
24       $10220789          3           15.0            4.158
25       $16629249          3           15.0            4.280
26        $3788390         15           15.0            5.885
27        $4988562         10           15.0            5.063
28       $13413049          9           15.0            4.650
29       $19325482         13           15.0            5.084
30        $7660857          9           15.0            5.072
31         $740410          6           15.0            4.518
32        $6372911         21           15.0            6.853
33       $19725756         12           15.0            5.274
34        $5580993          5           15.0            4.495
35        $2132739         20           15.0            6.042
36       $11124419         23           15.0            6.914
37       $16044797         11           15.0            4.773
38        $3699966         20           15.0            6.356
39       $18973085         12           15.0            5.330
40       $15988940          9           15.0            4.471

      Company RRR(%) 2.5
      Payment Policy (workdays)15
      Holdback Amount (%)15.0
      Holdback released after completion (days) 45

      Average Markup (%) 5.5
      Standard Deviation of Markups 1.02
      Confidence  (95%) +/- 0.33
```

Table D-6: Monte Carlo simulation of 40 runs for payment policy = 20 workdays

```
Run   Project Cost     Duration   Payment(days)   Markup(%)
***   ************     ********   *************   *********
 1        $6583151         12           20.0          5.695
 2        $3350993         11           20.0          5.825
 3       $18439934         11           20.0          6.036
 4        $1070992          7           20.0          4.795
 5       $12935755         10           20.0          5.147
 6       $18816270         23           20.0          7.551
 7       $17848153         18           20.0          6.463
 8        $1967294         25           20.0          7.322
 9        $7270685         25           20.0          7.955
10       $18607502         18           20.0          6.791
11       $13175138          3           20.0          3.941
12       $18311612         21           20.0          7.087
13        $9655069          9           20.0          5.084
14       $18511749         21           20.0          7.512
15        $8615138         18           20.0          7.457
16        $5346336          7           20.0          4.606
17        $4130205          5           20.0          4.645
18       $10506748         14           20.0          6.205
19        $4082329          6           20.0          5.008
20       $12194967         24           20.0          8.049
21        $2546369         20           20.0          7.796
22       $14379214          8           20.0          4.982
23        $3490548         13           20.0          5.986
24       $13091269         19           20.0          6.663
25        $4817740         18           20.0          7.164
26       $10514076         16           20.0          6.855
27        $6753973          4           20.0          4.378
28        $6249966          4           20.0          5.028
29       $15138563          8           20.0          5.050
30        $2481883         12           20.0          5.618
31       $18066852          9           20.0          5.279
32        $3178048          8           20.0          4.789
33       $19507057         21           20.0          7.318
34       $12306679          6           20.0          4.666
35        $3898151         14           20.0          6.061
36        $6370308         14           20.0          5.868
37        $8201507         19           20.0          6.234
38       $18050242         23           20.0          7.590
39       $13113906          4           20.0          4.463
40        $1201266          3           20.0          4.355

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 6.0
        Standard Deviation of Markups 1.19
        Confidence  (95%) +/- 0.38
```

Table D-7: Monte Carlo simulation of 40 runs for payment policy = 30 workdays

```
Run    Project Cost      Duration   Payment(days)     Markup(%)
***    ************      ********   **************    *********
 1       $8212603           25          30.0            8.992
 2       $5859486            9          30.0            6.727
 3       $8051713           19          30.0            8.887
 4      $13500035           18          30.0            7.590
 5      $12468083            8          30.0            6.537
 6      $13700172           18          30.0            8.675
 7       $3491712           11          30.0            7.185
 8       $4362774           15          30.0            7.888
 9      $18707673           21          30.0            8.012
10       $9523185           21          30.0            7.845
11      $10723357           17          30.0            7.440
12      $11211405            9          30.0            6.019
13       $9187398            7          30.0            6.138
14       $5459212           10          30.0            6.332
15      $18068016            6          30.0            5.916
16       $4171267           21          30.0            8.524
17      $17524111           12          30.0            6.825
18      $13015241           11          30.0            6.835
19       $9566987            3          30.0            5.428
20      $13031200           18          30.0            8.145
21      $17951577            7          30.0            6.169
22      $17199557            9          30.0            6.286
23      $12943426           25          30.0            9.398
24       $2022842           16          30.0            7.514
25      $14383632           14          30.0            6.997
26       $5086130            7          30.0            5.530
27        $645821            7          30.0            5.872
28       $7086199           21          30.0            8.151
29      $11014521           18          30.0            8.049
30      $16895036            7          30.0            6.433
31       $7990480           20          30.0            9.126
32      $11638871            4          30.0            5.934
33       $3478356           11          30.0            6.382
34      $14815173            3          30.0            5.343
35       $1446369            5          30.0            6.197
36       $2926472           13          30.0            7.381
37       $2206369            6          30.0            5.332
38       $1341335           24          30.0            9.105
39       $3037534           15          30.0            7.812
40       $6005719           11          30.0            6.494

         Company RRR(%) 2.5
         Payment Policy (workdays)30
         Holdback Amount (%)15.0
         Holdback released after completion (days) 45

         Average Markup (%) 7.1
         Standard Deviation of Markups 1.17
         Confidence  (95%) +/- 0.37
```

Table D-8: Monte Carlo simulation of 40 runs for payment policy = 40 workdays

```
Run   Project Cost     Duration    Payment(days)   Markup(%)
***   ************     ********    *************   *********
 1        $7706369        10           40.0          7.979
 2       $11305582        15           40.0          9.173
 3       $19450138        24           40.0          9.977
 4       $14977912        10           40.0          7.879
 5       $11961849        15           40.0          8.529
 6       $11209829        18           40.0          9.084
 7        $6953698        10           40.0          7.362
 8       $11905993        13           40.0          8.559
 9       $18201440         6           40.0          7.431
10        $3376471        11           40.0          7.798
11        $2592533        22           40.0          9.434
12        $9032911        13           40.0          7.918
13        $5024793         3           40.0          7.011
14        $7248938         5           40.0          6.497
15       $17873631        18           40.0          9.068
16        $1992772        25           40.0         10.261
17       $17017878        19           40.0          9.732
18        $5169074        24           40.0          9.535
19        $1436163         8           40.0          7.244
20        $6572636         4           40.0          6.228
21       $17445344        14           40.0          8.463
22        $3116403        15           40.0          8.516
23       $16405412        24           40.0         10.431
24       $11437158        13           40.0          8.133
25        $2284588         5           40.0          6.892
26        $8661130        13           40.0          8.533
27        $2236711         6           40.0          7.367
28        $6692979        13           40.0          8.183
29       $10508288        25           40.0         10.883
30       $14404692         8           40.0          7.601
31       $11452466        19           40.0          9.098
32        $1523937        25           40.0          9.882
33        $2972122        18           40.0          9.834
34         $732019         9           40.0          7.079
35        $6779451         4           40.0          7.143
36       $14211884        10           40.0          7.024
37        $3571232        13           40.0          8.146
38       $10443801        18           40.0          9.264
39       $18092330         8           40.0          7.390
40       $19076406        20           40.0          9.888

        Company RRR(%) 2.5
        Payment Policy (workdays)40
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 8.4
        Standard Deviation of Markups 1.18
        Confidence  (95%) +/- 0.38
```

Table D-9: Monte Carlo simulation of 40 runs for payment policy = 50 workdays

```
Run    Project Cost      Duration    Payment(days)    Markup(%)
***    ************      ********    *************    *********
 1       $7613423            4           50.0           7.943
 2       $8349485           17           50.0           9.856
 3       $3597327           13           50.0           9.599
 4       $6069485           13           50.0           9.821
 5       $6029588           18           50.0          10.151
 6       $6156608            5           50.0           7.834
 7      $12813082            3           50.0           8.141
 8      $16773322           14           50.0           9.736
 9      $12581027           12           50.0           8.661
10      $19949624           13           50.0           9.024
11      $18485480           12           50.0           8.866
12      $19653734           16           50.0           9.845
13      $18621782            6           50.0           8.309
14      $19853871           16           50.0           9.653
15      $13925479            5           50.0           8.300
16      $16581815           20           50.0          10.213
17      $11397465            3           50.0           7.370
18      $19956953           15           50.0           9.590
19       $9564314           16           50.0          10.496
20      $13708733           19           50.0          10.735
21       $8028355            6           50.0           8.567
22      $15892980            3           50.0           7.888
23       $8972533           23           50.0          10.655
24      $14605034           14           50.0          10.014
25       $8428629            5           50.0           7.794
26      $10156746           11           50.0           8.646
27      $10364862           14           50.0           9.707
28      $13829075            6           50.0           8.795
29       $1091299           17           50.0           9.781
30      $19868528           20           50.0          10.154
31       $4019587           18           50.0          10.441
32      $12628253            9           50.0           9.229
33       $5459793            8           50.0           8.739
34      $10164075           13           50.0           8.749
35       $9380136           24           50.0          11.441
36       $1647087            3           50.0           8.081
37      $13511849            5           50.0           7.415
38      $15735993            7           50.0           8.425
39      $10487808            7           50.0           8.655
40      $18416268           10           50.0           8.585

         Company RRR(%) 2.5
         Payment Policy (workdays)50
         Holdback Amount (%)15.0
         Holdback released after completion (days) 45

         Average Markup (%) 9.1
         Standard Deviation of Markups 1.01
         Confidence  (95%) +/- 0.32
```

Appendix E: Sensitivity to the Cost Category Labour

Monte Carlo Study for Sensitivity Analysis of Cash Flow Model to the Cost Category Labour

The cost of the labour category is varied from 10% to 60% of the total project cost with the recommended markup determined by the cash flow analysis model. The values for other variables which are held constant are shown below. The monte carlo study is simulated for 40 runs randomly generating project duration, total cost and cost distribution of remaining categories for each run. The results for each 40 run simulation are provided in Tables E-3 to E-6 with the average markup, standard deviation and 95% confidence interval calculated for each table. A summary of the Monte Carlo study is shown in Table E-1.

External Variables:

Payment Policy =	20 workdays
RRR =	2.5
Holdback =	15%
Billing Factor =	1.0

Payroll Burden is 24% of labour amount

Table E-1: Summary of Monte Carlo study for labour category

Labour Costs (%)	Average Markup (%)	Confidence Interval	Upper Limit	Lower Limit
10	6.0	0.42	6.42	5.58
20	5.9	0.36	6.26	5.54
40	6.1	0.35	6.45	5.75
60	6.1	0.35	6.45	5.75

The quantile quantile (q-q) plot is produces for each 40 run simulation to check for normality. If the plot presents a linear pattern then the accuracy of the 95% confidence interval is proved. The data for the q-q plots is contained in Table E-2 with the plots shown in Figures E-1 to E-4.

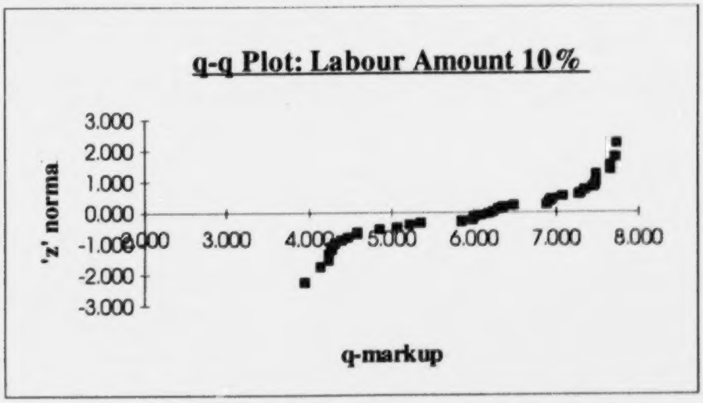

Figure E-1: Q-Q plot for simulation of labour cost = 10 %

Table E-2: Data for quantile-quantile plots for labour cost analysis

	Labour Amount (%), (X)					
#	10	20	40	60	Phi	'z' (Y)
1	3.956	4.083	4.538	4.747	0.013	-2.240
2	4.148	4.226	4.555	4.808	0.038	-1.780
3	4.230	4.268	4.746	4.901	0.063	-1.535
4	4.234	4.291	4.906	4.933	0.088	-1.355
5	4.270	4.469	4.975	4.939	0.113	-1.213
6	4.286	4.529	5.044	4.940	0.138	-1.092
7	4.317	4.589	5.047	5.031	0.163	-0.985
8	4.392	4.774	5.050	5.052	0.188	-0.888
9	4.467	4.784	5.055	5.064	0.213	-0.798
10	4.588	4.876	5.163	5.066	0.238	-0.715
11	4.592	4.913	5.220	5.217	0.263	-0.635
12	4.858	5.013	5.224	5.284	0.288	-0.560
13	5.063	5.275	5.283	5.327	0.313	-0.490
14	5.218	5.406	5.310	5.370	0.338	-0.420
15	5.346	5.444	5.316	5.397	0.363	-0.352
16	5.849	5.483	5.324	5.560	0.388	-0.285
17	5.979	5.487	5.558	5.690	0.413	-0.221
18	5.997	5.561	5.571	5.702	0.438	-0.157
19	6.092	5.706	5.576	5.814	0.463	-0.094
20	6.179	5.725	5.582	5.870	0.488	-0.031
21	6.241	6.067	5.683	5.909	0.513	0.031
22	6.287	6.281	5.803	5.990	0.538	0.095
23	6.355	6.289	5.825	5.995	0.563	0.157
24	6.490	6.371	6.451	6.510	0.588	0.220
25	6.896	6.517	6.627	6.708	0.613	0.285
26	6.922	6.587	6.629	6.987	0.638	0.351
27	6.950	6.617	6.794	7.067	0.663	0.420
28	7.091	6.697	6.899	7.258	0.688	0.490
29	7.267	6.779	6.945	7.300	0.713	0.560
30	7.296	6.795	7.169	7.558	0.738	0.635
31	7.356	6.881	7.254	7.745	0.763	0.715
32	7.451	6.936	7.285	7.800	0.788	0.798
33	7.474	7.149	7.350	8.080	0.813	0.888
34	7.478	7.166	7.395	8.090	0.838	0.985
35	7.481	7.244	7.581	8.195	0.863	1.091
36	7.491	7.407	7.705	8.237	0.888	1.215
37	7.662	7.608	7.727	8.246	0.913	1.355
38	7.667	7.610	7.731	8.341	0.938	1.535
39	7.723	7.643	8.014	8.431	0.963	1.780
40	7.736	7.832	8.142	8.494	0.988	2.241

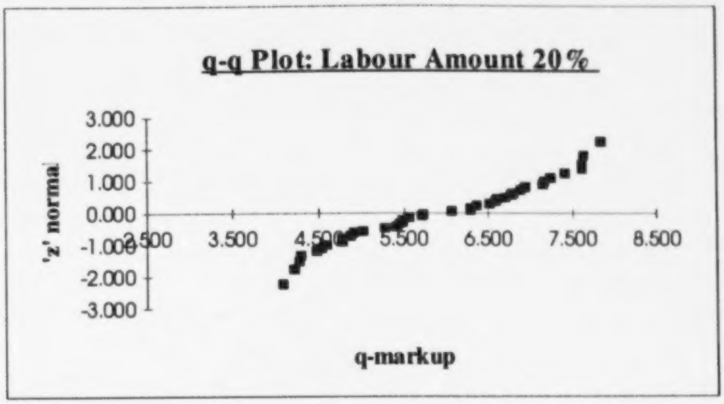

Figure E-2: Q-Q plot for simulation of labour cost = 20 %

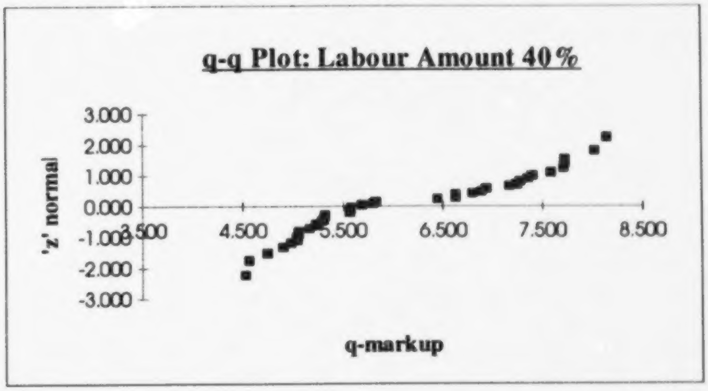

Figure E-3: Q-Q plot for simulation of labour cost = 40 %

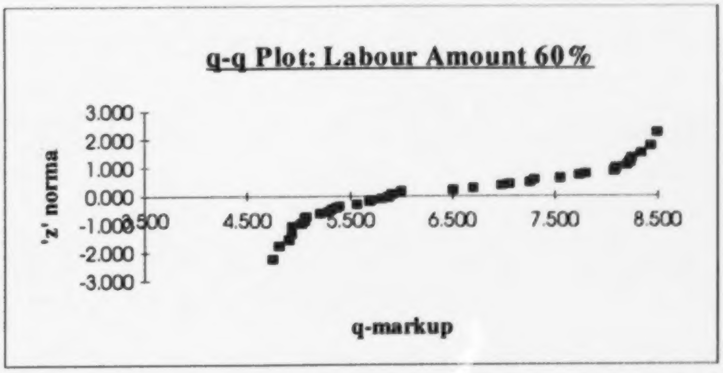

Figure E-4: Q-Q plot for simulation of labour cost = 60 %

Table E-3: Monte Carlo simulation of 40 runs for labour cost = 10 %

```
Run   Project Cost    Duration    Labour(%)       Markup(%)
***   ************    ********    *************   *********
 1      $13862256        19           10.0           6.355
 2       $1973555         6           10.0           4.270
 3        $501432        25           10.0           7.474
 4      $11005132         3           10.0           4.392
 5       $2588624         8           10.0           4.467
 6       $4276843        19           10.0           5.997
 7      $16381640        16           10.0           5.849
 8      $11125475        13           10.0           5.346
 9       $4693076        25           10.0           7.267
10      $16301845         3           10.0           4.317
11       $4624515        24           10.0           7.091
12      $17225339        17           10.0           6.241
13      $16433421        25           10.0           7.356
14      $14153421        21           10.0           7.478
15       $2760747         3           10.0           4.234
16      $17345681         4           10.0           4.148
17      $14881503         8           10.0           4.588
18      $10929242        23           10.0           6.949
19       $5177049        24           10.0           7.451
20      $15680750        25           10.0           7.662
21      $18857051        24           10.0           7.491
22       $1016021        12           10.0           5.063
23       $1528007        15           10.0           6.287
24      $15801092        12           10.0           4.858
25       $9368694        24           10.0           7.667
26       $3319309        25           10.0           7.736
27       $1535336        17           10.0           6.179
28       $6199720         4           10.0           3.956
29       $1751432        24           10.0           7.296
30      $19000682        20           10.0           6.950
31      $15544448         9           10.0           4.592
32      $14256503        20           10.0           6.922
33       $5726981        17           10.0           6.092
34      $13367530         4           10.0           4.286
35      $11895406        23           10.0           6.896
36        $998761        24           10.0           7.481
37      $15767873        17           10.0           5.979
38      $17456092         5           10.0           4.230
39      $10031639        25           10.0           7.723
40       $2818556        11           10.0           5.218

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 6.0
        Standard Deviation of Markups 1.31
        Confidence  (95%) +/- 0.42
```

Table E-4: Monte Carlo simulation of 40 runs for labour cost = 20 %

Run	Project Cost	Duration	Labour(%)	Markup(%)
1	$19096777	7	20.0	4.529
2	$11176296	8	20.0	4.876
3	$5735953	12	20.0	5.406
4	$10400337	22	20.0	6.697
5	$5952049	19	20.0	6.779
6	$13307941	21	20.0	7.407
7	$13508078	20	20.0	6.289
8	$627322	15	20.0	6.067
9	$9755954	12	20.0	5.444
10	$9460063	16	20.0	6.587
11	$7987940	12	20.0	5.275
12	$747665	24	20.0	7.608
13	$13731502	6	20.0	4.784
14	$11763351	6	20.0	4.469
15	$4338898	3	20.0	4.083
16	$14955612	12	20.0	5.483
17	$8523214	24	20.0	7.610
18	$4259103	13	20.0	5.487
19	$18348010	17	20.0	6.795
20	$15075955	21	20.0	6.617
21	$4562323	12	20.0	5.561
22	$18155202	20	20.0	6.936
23	$6762529	25	20.0	7.166
24	$5474583	14	20.0	5.725
25	$3010405	18	20.0	6.517
26	$2714514	21	20.0	7.149
27	$16491571	22	20.0	6.881
28	$13531365	6	20.0	4.589
29	$18578764	5	20.0	4.268
30	$16610612	5	20.0	4.291
31	$9186159	25	20.0	7.643
32	$19802873	11	20.0	5.706
33	$13370475	23	20.0	7.244
34	$17042804	18	20.0	6.281
35	$15258831	10	20.0	4.774
36	$8330406	4	20.0	4.226
37	$17174380	17	20.0	6.371
38	$11238009	25	20.0	7.832
39	$19374586	8	20.0	4.913
40	$14430270	8	20.0	5.013

Company RRR(%) 2.5
Payment Policy (workdays)20
Holdback Amount (%)15.0
Holdback released after completion (days) 45

Average Markup (%) 5.9
Standard Deviation of Markups 1.13
Confidence (95%) +/- 0.36

Table E-5: Monte Carlo simulation of 40 runs for labour cost = 40 %

```
Run    Project Cost    Duration    Labour(%)       Markup(%)
***    ************    ********    *************   *********
 1       $9230816         16          40.0           6.451
 2       $5278555          9          40.0           5.576
 3       $7462802         15          40.0           6.629
 4       $4502596         23          40.0           7.727
 5      $19271708         16          40.0           6.794
 6      $11238214          9          40.0           5.316
 7       $3813760          7          40.0           5.224
 8       $2837664         22          40.0           7.731
 9       $7998076          5          40.0           4.906
10      $19606845          6          40.0           5.047
11      $17822872         21          40.0           7.169
12      $10894447         14          40.0           5.825
13      $10102529         22          40.0           7.285
14       $6037254          7          40.0           5.055
15      $14173831         12          40.0           5.582
16       $1293075          7          40.0           5.044
17      $18358146         10          40.0           5.558
18      $14405886          3          40.0           4.538
19      $16590132         10          40.0           5.571
20       $5693487         11          40.0           5.683
21       $5213418         23          40.0           7.350
22      $18494448          4          40.0           4.746
23      $19006434          7          40.0           5.220
24      $13750269          4          40.0           4.555
25       $7317871         16          40.0           6.899
26       $1268486         17          40.0           6.945
27      $15357393         22          40.0           7.581
28      $20021777          9          40.0           5.283
29      $15573488          5          40.0           5.050
30      $13293488         24          40.0           8.142
31       $9837255         13          40.0           5.803
32       $8549309         24          40.0           8.014
33      $19377393         22          40.0           7.705
34       $7488693          8          40.0           5.163
35      $17609379         21          40.0           7.395
36      $18305544         17          40.0           6.627
37       $9889035         22          40.0           7.254
38      $11577255          9          40.0           5.324
39       $4152802          7          40.0           4.975
40       $6833076          9          40.0           5.310

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 6.1
        Standard Deviation of Markups 1.11
        Confidence  (95%) +/- 0.35
```

Table E-6: Monte Carlo simulation of 40 runs for labour cost = 60 %

```
Run   Project Cost     Duration     Labour(%)       Markup(%)
***   ************     ********   *************     *********
 1      $17818351         10           60.0           5.870
 2       $9897870         11           60.0           5.995
 3       $8113898          4           60.0           4.808
 4       $9121911          3           60.0           4.747
 5       $4673623         22           60.0           8.237
 6      $12201159         24           60.0           8.246
 7        $808485          7           60.0           5.370
 8      $15393419          7           60.0           5.217
 9       $4992801          5           60.0           5.066
10       $4696911          9           60.0           5.690
11       $3224787          5           60.0           5.052
12      $19793831         12           60.0           5.990
13      $15033693          5           60.0           4.933
14      $13065542          5           60.0           4.940
15       $5641089         25           60.0           8.431
16      $10192460          5           60.0           5.064
17      $11696501         23           60.0           8.341
18      $15368830         18           60.0           7.300
19      $13584857         10           60.0           5.814
20       $6656432          3           60.0           4.939
21       $2208143         23           60.0           8.080
22      $19457393         19           60.0           7.558
23      $19657530         19           60.0           7.258
24      $16584310         19           60.0           6.987
25      $14120131         22           60.0           7.745
26      $13824241          3           60.0           4.901
27       $4415678         16           60.0           6.510
28       $5111842         11           60.0           5.909
29       $4631774         22           60.0           8.195
30      $17912803          4           60.0           5.031
31      $18424790          7           60.0           5.397
32       $1575814         10           60.0           5.560
33      $14672666         22           60.0           7.800
34       $8451637         23           60.0           8.090
35       $6667664         15           60.0           6.708
36      $19268489          9           60.0           5.702
37      $18476571         16           60.0           7.067
38      $12540200         24           60.0           8.494
39       $1147527          7           60.0           5.284
40      $15732461          7           60.0           5.327

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 6.3
        Standard Deviation of Markups 1.29
        Confidence  (95%) +/- 0.41
```

Single Project Sensitivity Analysis of Cash Flow Model to Labour Costs

The labour cost is varied from 10% to 60% of the total project cost of a single project with the recommended markup determined by the cash flow analysis model. The values for other parameters and cost categories are shown as external and cost variables below. The sensitivity analysis is performed using the project S-curve tabulated in Table E-7 with the results of the analysis shown in Table E-8.

Cost Variables:

Labour = variable
PRB = 24% of labor
Material = 35%
Equipment = 30%
Operating Costs = 20%
Indirect Overhead = 15%

External Variables:

Payment Policy = 20 wk dys
RRR = 2.0%
Holdback = 15%
Billing Factor = 1.0
HOOH = $0

The labour cost item is paid out 50% at mid-month and the remaining 50% of period total at the end of the month. The initial cost of the project in period zero is considered an indirect overhead expense. As labour cost is varied the PRB changes accordingly and the cost per period remaining (after removing labour and PRB) is distributed according to the allocated percentage of other cost categories.

Table E-7: Project S-curve for single project sensitivity analysis

Date	Period	Cost	Cummulative
Sep-92	0	$12,204.00	$12,204.00
Oct-92	1	$21,276.00	$33,480.00
Nov-92	2	$1,030,000.00	$1,063,480.00
Dec-92	3	$1,190,000.00	$2,253,480.00
Jan-93	4	$1,090,000.00	$3,343,480.00
Feb-93	5	$190,000.00	$3,533,480.00
Mar-93	6	$450,000.00	$3,983,480.00
Apr-93	7	$500,000.00	$4,483,480.00
May-93	8	$210,970.00	$4,694,450.00
Jun-93	9	$34,025.00	$4,728,475.00

Table E-8: Results for single project sensitivity analysis for labour

Labour	Markup
10%	3.1%
20%	3.2%
40%	3.5%
60%	3.7%

The calculation of markup for each labour amount is shown in Tables E-9 to E-16.

Table E-9: Cash outflow single project present value for labour amount = 10%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$1,064	$1,064	0.99	$1,053
1.0	$511	$3,728	$2,796			$1,064	$8,098	0.98	$7,939
1.5				$6,523	$5,591	$51,500	$63,615	0.97	$61,753
2.0	$24,720	$180,456	$135,342			$51,500	$392,018	0.96	$376,795
2.5				$315,798	$270,684	$59,500	$645,982	0.95	$614,780
3.0	$28,560	$208,488	$156,366			$59,500	$452,914	0.94	$426,791
3.5				$364,854	$312,732	$54,500	$732,086	0.93	$683,064
4.0	$26,160	$190,968	$143,226			$54,500	$414,854	0.92	$383,261
4.5				$334,194	$286,452	$9,500	$630,146	0.91	$576,422
5.0	$4,560	$33,288	$24,966			$9,500	$72,314	0.91	$65,497
5.5				$58,254	$49,932	$22,500	$130,686	0.90	$117,200
6.0	$10,800	$78,840	$59,130			$22,500	$171,270	0.89	$152,083
6.5				$137,970	$118,260	$25,000	$281,230	0.88	$247,264
7.0	$12,000	$87,600	$65,700			$25,000	$190,300	0.87	$165,668
7.5				$153,300	$131,400	$10,549	$295,249	0.86	$254,499
8.0	$5,063	$36,962	$27,721			$10,549	$80,295	0.85	$68,531
8.5				$64,683	$55,443	$1,701	$121,828	0.85	$102,954
9.0	$817	$5,961	$4,471			$1,701	$12,950	0.84	$10,836
9.5	$0	$0	$0	$10,432	$8,942	$0	$19,374	0.83	$16,051
							PVout =		$4,344,646

Table E-10: Cash inflow single project present value for labour amount = 10%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117
			Total =	$709,271		PV in =		$4,215,208

Markup for 10% Labour = (4344646 / 4215208) -1 = 3.1%

Table E-11: Cash outflow single project present value for labour amount = 20%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$2,128	$2,128	0.99	$2,107
1.0	$1,021	$3,200	$2,400			$2,128	$8,749	0.98	$8,577
1.5				$5,600	$4,800	$103,000	$113,400	0.97	$110,081
2.0	$49,440	$154,912	$116,184			$103,000	$423,536	0.96	$407,090
2.5				$271,096	$232,368	$119,000	$622,464	0.95	$592,398
3.0	$57,120	$178,976	$134,232			$119,000	$489,328	0.94	$461,105
3.5				$313,208	$268,464	$109,000	$690,672	0.93	$644,423
4.0	$52,320	$163,936	$122,952			$109,000	$448,208	0.92	$414,075
4.5				$286,888	$245,904	$19,000	$551,792	0.91	$504,748
5.0	$9,120	$28,576	$21,432			$19,000	$78,128	0.91	$70,763
5.5				$50,008	$42,864	$45,000	$137,872	0.90	$123,645
6.0	$21,600	$67,680	$50,760			$45,000	$185,040	0.89	$164,310
6.5				$118,440	$101,520	$50,000	$269,960	0.88	$237,355
7.0	$24,000	$75,200	$56,400			$50,000	$205,600	0.87	$178,987
7.5				$131,600	$112,800	$21,097	$265,497	0.86	$228,854
8.0	$10,127	$31,730	$23,797			$21,097	$86,751	0.85	$74,041
8.5				$55,527	$47,595	$3,403	$106,525	0.85	$90,022
9.0	$1,633	$5,117	$3,838			$3,403	$13,991	0.84	$11,707
9.5	$0	$0	$0	$8,955	$7,676	$0	$16,631	0.83	$13,779
							PVout =		$4,350,271

Table E-12: Cash inflow single project present value for labour amount = 20%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117
			Total =	$709,271		PV in =		$4,215,208

Markup for 20% Labour = (4350271 / 4215208) -1 = 3.2%

Table E-13: Cash outflow single project present value for labour amount = 40%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$4,255	$4,255	0.99	$4,213
1.0	$2,042	$2,145	$1,608			$4,255	$10,051	0.98	$9,854
1.5				$3,753	$3,217	$206,000	$212,970	0.97	$206,737
2.0	$98,880	$103,824	$77,868			$206,000	$486,572	0.96	$467,678
2.5				$181,692	$155,736	$238,000	$575,428	0.95	$547,634
3.0	$114,240	$119,952	$89,964			$238,000	$562,156	0.94	$529,732
3.5				$209,916	$179,928	$218,000	$607,844	0.93	$567,142
4.0	$104,640	$109,872	$82,404			$218,000	$514,916	0.92	$475,703
4.5				$192,276	$164,808	$38,000	$395,084	0.91	$361,400
5.0	$18,240	$19,152	$14,364			$38,000	$89,756	0.91	$81,295
5.5				$33,516	$28,728	$90,000	$152,244	0.90	$136,534
6.0	$43,200	$45,360	$34,020			$90,000	$212,580	0.89	$188,765
6.5				$79,380	$68,040	$100,000	$247,420	0.88	$217,537
7.0	$48,000	$50,400	$37,800			$100,000	$236,200	0.87	$205,626
7.5				$88,200	$75,600	$42,194	$205,994	0.86	$177,563
8.0	$20,253	$21,266	$15,949			$42,194	$99,662	0.85	$85,061
8.5				$37,215	$31,899	$6,805	$75,919	0.85	$64,158
9.0	$3,266	$3,430	$2,572			$6,805	$16,073	0.84	$13,450
9.5	$0	$0	$0	$6,002	$5,145	$0	$11,147	0.83	$9,235
							PVout =		$4,361,520

Table E-14: Cash inflow single project present value for labour amount = 40%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117
			Total =	$709,271		PV in =		$4,215,208

Markup for 40% Labour = (4361520 / 4215208) -1 = 3.5%

Table E-15: Cash outflow single project present value for labour amount = 60%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$6,383	$6,383	0.99	$6,320
1.0	$3,064	$1,089	$817			$6,383	$11,353	0.98	$11,130
1.5				$1,906	$1,634	$309,000	$312,540	0.97	$303,393
2.0	$148,320	$52,736	$39,552			$309,000	$549,608	0.96	$528,266
2.5				$92,288	$79,104	$357,000	$528,392	0.95	$502,870
3.0	$171,360	$60,928	$45,696			$357,000	$634,984	0.94	$598,360
3.5				$106,624	$91,392	$327,000	$525,016	0.93	$489,860
4.0	$156,960	$55,808	$41,856			$327,000	$581,624	0.92	$537,331
4.5				$97,664	$83,712	$57,000	$238,376	0.91	$218,053
5.0	$27,360	$9,728	$7,296			$57,000	$101,384	0.91	$91,827
5.5				$17,024	$14,592	$135,000	$166,616	0.90	$149,422
6.0	$64,800	$23,040	$17,280			$135,000	$240,120	0.89	$213,220
6.5				$40,320	$34,560	$150,000	$224,880	0.88	$197,720
7.0	$72,000	$25,600	$19,200			$150,000	$266,800	0.87	$232,265
7.5				$44,800	$38,400	$63,291	$146,491	0.86	$126,273
8.0	$30,380	$10,802	$8,101			$63,291	$112,574	0.85	$96,080
8.5				$18,903	$16,202	$10,208	$45,313	0.85	$38,293
9.0	$4,900	$1,742	$1,307			$10,208	$18,156	0.84	$15,192
9.5	$0	$0	$0	$3,049	$2,613	$0	$5,662	0.83	$4,691
							PVout =		$4,372,769

Table E-16: Cash inflow single project present value for labour amount = 60%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117
			Total =	$709,271		PV in =		$4,215,208

Markup for 60% Labour = (4372769 / 4215208) -1 = 3.7%

Appendix F: Sensitivity to the Cost Category Materials

Monte Carlo Study for Sensitivity Analysis of Cash Flow Model to the Cost Category Materialsr

The cost of the material category is varied from 10% to 60% of the total project cost with the recommended markup determined by the cash flow analysis model. The values for other variables which are held constant are shown below. The monte carlo study is simulated for 40 runs randomly generating project duration, total cost and cost distribution of remaining categories for each run. The results for each 40 run simulation are provided in Tables F-3 to F-6 with the average markup, standard deviation and 95% confidence interval calculated for each table. A summary of the Monte Carlo study is shown in Table F-1.

External Variables:

Payment Policy =	20 workdays
RRR =	2.5
Holdback =	15%
Billing Factor =	1.0

Payroll Burden is 24% of labour amount

Table F-1: Summary of Monte Carlo study for material category

Material Costs (%)	Average Markup (%)	Confidence Interval	Upper Limit	Lower Limit
10	6.3	0.36	6.66	5.94
20	6.1	0.38	6.48	5.72
40	5.7	0.37	6.07	5.33
60	5.5	0.33	5.83	5.17

The quantile quantile (q-q) plot is produces for each 40 run simulation to check for normality. If the plot presents a linear pattern then the accuracy of the 95% confidence interval is proved. The data for the q-q plots is contained in Table F-2 with the plots shown in Figures F-1 to F-4.

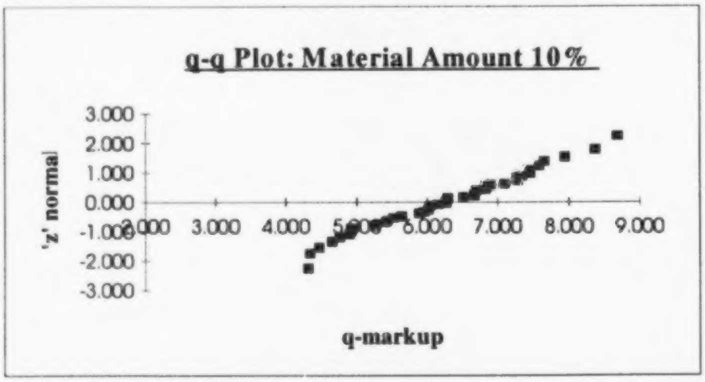

Figure F-1: Q-Q plot for simulation of material cost = 10 %

Table F-2: Data for quantile-quantile plots for material cost analysis

	Material Amount (%), (X)					
#	10	20	40	60	Phi	'z' (Y)
1	4.321	4.122	4.043	3.886	0.013	-2.240
2	4.350	4.510	4.248	3.899	0.038	-1.780
3	4.485	4.520	4.312	4.040	0.063	-1.535
4	4.658	4.559	4.411	4.238	0.088	-1.355
5	4.766	4.564	4.449	4.327	0.113	-1.213
6	4.910	4.645	4.473	4.378	0.138	-1.092
7	4.922	4.652	4.550	4.473	0.163	-0.985
8	4.923	4.709	4.571	4.486	0.188	-0.888
9	5.263	4.745	4.584	4.534	0.213	-0.798
10	5.410	4.801	4.616	4.565	0.238	-0.715
11	5.432	4.825	4.756	4.615	0.263	-0.635
12	5.530	4.842	4.822	4.623	0.288	-0.560
13	5.650	5.116	4.918	4.681	0.313	-0.490
14	5.899	5.279	4.962	4.699	0.338	-0.420
15	5.956	5.346	5.033	4.792	0.363	-0.352
16	6.018	5.702	5.056	4.993	0.388	-0.285
17	6.022	5.883	5.056	5.125	0.413	-0.221
18	6.040	5.939	5.150	5.235	0.438	-0.157
19	6.154	5.974	5.271	5.415	0.463	-0.094
20	6.260	6.136	5.289	5.435	0.488	-0.031
21	6.262	6.300	5.591	5.462	0.513	0.031
22	6.284	6.410	5.780	5.485	0.538	0.095
23	6.523	6.452	5.851	5.532	0.563	0.157
24	6.677	6.484	5.856	5.534	0.588	0.220
25	6.678	6.513	5.892	5.542	0.613	0.285
26	6.702	6.547	6.141	5.569	0.638	0.351
27	6.841	6.617	6.182	5.899	0.663	0.420
28	6.860	6.709	6.209	5.932	0.688	0.490
29	6.887	6.870	6.469	5.973	0.713	0.560
30	7.103	6.902	6.498	6.042	0.738	0.635
31	7.279	7.007	6.704	6.411	0.763	0.715
32	7.289	7.120	6.998	6.643	0.788	0.798
33	7.347	7.204	7.102	6.838	0.813	0.888
34	7.453	7.458	7.257	6.923	0.838	0.985
35	7.457	7.575	7.469	6.968	0.863	1.091
36	7.589	7.660	7.476	7.048	0.888	1.215
37	7.659	7.740	7.574	7.080	0.913	1.355
38	7.944	7.773	7.587	7.240	0.938	1.535
39	8.373	8.234	7.597	7.245	0.963	1.780
40	8.698	8.293	7.746	7.361	0.988	2.241

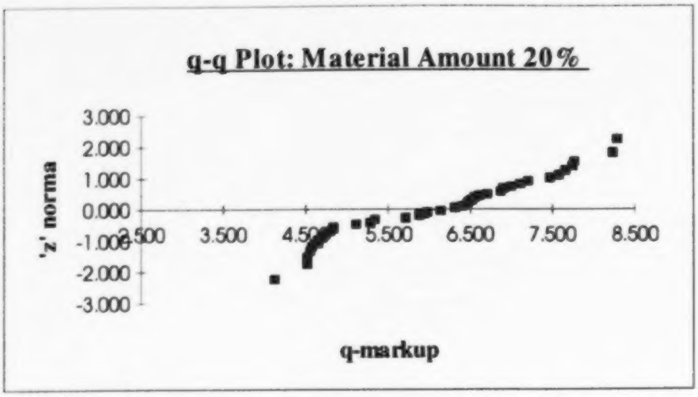

Figure F-2: Q-Q plot for simulation of material cost = 20 %

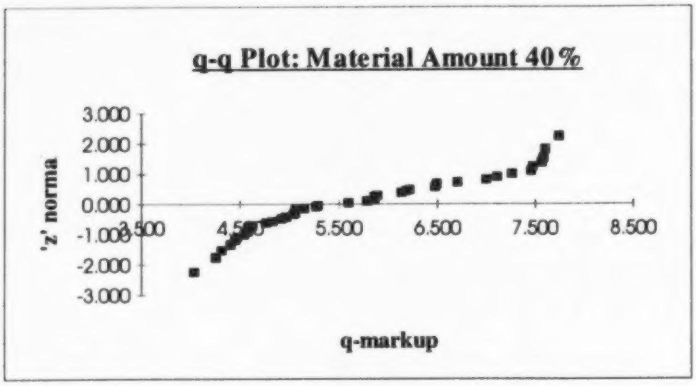

Figure F-3: Q-Q plot for simulation of material cost = 40 %

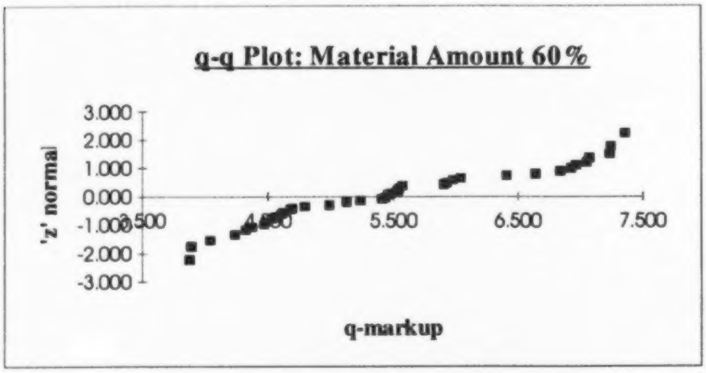

Figure F-4: Q-Q plot for simulation of material cost = 60 %

Table F-3: Monte Carlo simulation of 40 runs for material cost = 10 %

```
Run    Project Cost     Duration     Material(%)      Markup(%)
***    ************     ********    *************     *********
 1      $13159515           3           10.0            4.321
 2       $4927185          24           10.0            8.373
 3       $7111431           8           10.0            5.263
 4       $4151225          15           10.0            5.899
 5      $15263967          20           10.0            7.457
 6      $14995269          20           10.0            7.103
 7      $11227186           5           10.0            4.766
 8      $10251090          20           10.0            7.589
 9       $7475062          20           10.0            7.347
10       $3210951           9           10.0            5.410
11      $17299858          13           10.0            6.677
12      $18307872          13           10.0            6.018
13       $5923144           3           10.0            4.658
14      $19516023          11           10.0            6.022
15       $9994446          17           10.0            6.154
16       $5050130          17           10.0            6.678
17      $17835132           3           10.0            4.350
18      $13882871          18           10.0            6.284
19      $16067118          25           10.0            7.944
20      $16763283          20           10.0            7.453
21      $16283214           9           10.0            5.650
22       $8249719          25           10.0            7.659
23       $4481637          10           10.0            5.432
24      $15098351          19           10.0            7.289
25       $8665952           8           10.0            5.530
26        $745471           9           10.0            4.922
27      $14834378          14           10.0            6.260
28      $11562323          18           10.0            6.523
29      $10770405          25           10.0            8.698
30       $4834034          10           10.0            6.040
31      $14841707          16           10.0            6.860
32       $9897391          16           10.0            6.887
33      $19026023          14           10.0            6.262
34      $18730132          17           10.0            6.841
35       $9321569           7           10.0            4.923
36       $6361363          15           10.0            6.702
37       $1601225           8           10.0            4.910
38      $19162324           8           10.0            4.485
39       $6874034          21           10.0            7.279
40       $5897938          13           10.0            5.956

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 6.3
        Standard Deviation of Markups 1.13
        Confidence  (95%) +/- 0.36
```

Table F-4: Monte Carlo simulation of 40 runs for material cost = 20 %

```
Run   Project Cost     Duration    Material(%)     Markup(%)
***   ************     ********   *************    *********
 1       $5702527          8           20.0           5.116
 2       $5718486         16           20.0           6.300
 3      $11870952         14           20.0           5.883
 4       $4942526          7           20.0           4.652
 5      $15159651         20           20.0           7.007
 6       $9223280          5           20.0           4.825
 7       $9423417          5           20.0           4.520
 8       $4479101          5           20.0           4.709
 9      $13607733          3           20.0           4.559
10       $9655472         18           20.0           5.939
11      $11839719         25           20.0           7.575
12        $943073          4           20.0           4.112
13      $12055815          9           20.0           5.702
14       $4022320         25           20.0           8.293
15      $16127117         22           20.0           7.773
16      $18807391         25           20.0           7.660
17      $16031364         25           20.0           7.458
18      $19703693         20           20.0           7.204
19      $17919720         13           20.0           6.136
20      $10991294          6           20.0           4.801
21       $6543006         25           20.0           8.234
22       $2477731         10           20.0           5.346
23      $14270678          4           20.0           4.842
24       $9326362          4           20.0           4.645
25       $6862184          8           20.0           4.510
26      $14502733         18           20.0           6.709
27      $13030610         14           20.0           6.452
28       $5790334          3           20.0           4.564
29       $5310266         14           20.0           6.410
30      $14934925          8           20.0           5.279
31       $9381568          5           20.0           4.745
32      $19998282         14           20.0           5.974
33      $17222254         14           20.0           6.484
34      $17238213         21           20.0           6.870
35       $3861430         19           20.0           6.547
36        $589375         23           20.0           7.740
37      $15670336         20           20.0           6.513
38      $13390336         16           20.0           6.617
39       $3697115         21           20.0           6.902
40      $18282049         22           20.0           7.120

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 6.1
        Standard Deviation of Markups 1.20
        Confidence  (95%) +/- 0.38
```

Table F-5: Monte Carlo simulation of 40 runs for material cost = 40 %

```
Run    Project Cost    Duration    Material(%)     Markup(%)
***    ************    ********   *************    *********
 1         $5363690       16          40.0           5.856
 2         $5067800       19          40.0           7.102
 3        $15188487        9          40.0           5.289
 4        $15884651        5          40.0           4.550
 5         $7468143       10          40.0           5.272
 6         $5499992       10          40.0           5.056
 7        $11539445       23          40.0           7.469
 8         $2626909        9          40.0           4.918
 9        $15723761       22          40.0           7.476
10        $11459650       10          40.0           5.078
11         $6019307       15          40.0           5.591
12        $10683691       25          40.0           7.587
13        $19699309       15          40.0           6.209
14        $13762938       23          40.0           7.746
15         $2370265        6          40.0           4.571
16        $16955199        6          40.0           4.584
17         $6554581        4          40.0           4.312
18         $6258690        8          40.0           5.150
19         $4786567        4          40.0           4.411
20         $1826361       11          40.0           5.271
21        $16595473        4          40.0           4.449
22        $14627322        4          40.0           4.248
23         $7202869       24          40.0           7.574
24         $1946703       21          40.0           6.998
25         $5150197       16          40.0           5.892
26        $16758966       17          40.0           6.498
27        $14974993        9          40.0           4.962
28         $8046568       25          40.0           7.597
29         $7254650       10          40.0           5.003
30         $4974649        6          40.0           4.616
31         $1518416       18          40.0           6.704
32         $8166910       12          40.0           5.851
33         $5702731       16          40.0           6.182
34        $15214377       25          40.0           7.257
35         $9462184        3          40.0           4.043
36         $6501978       10          40.0           4.822
37         $6021910       22          40.0           6.469
38        $19302939        3          40.0           4.473
39        $19814926        6          40.0           4.756
40        $10902390       15          40.0           6.141

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 5.7
        Standard Deviation of Markups 1.15
        Confidence  (95%) +/- 0.37
```

Table F-6: Monte Carlo simulation of 40 runs for material cost = 60 %

Run	Project Cost	Duration	Material(%)	Markup(%)
***	************	********	*************	*********
1	$18897904	7	60.0	4.615
2	$18913863	14	60.0	5.435
3	$9817149	8	60.0	4.623
4	$2888724	24	60.0	7.245
5	$14313315	10	60.0	4.681
6	$8376944	18	60.0	5.973
7	$11071876	25	60.0	7.048
8	$14063999	9	60.0	4.792
9	$11599821	12	60.0	5.542
10	$15584000	11	60.0	4.699
11	$14111876	7	60.0	4.327
12	$11151670	15	60.0	5.415
13	$18608041	9	60.0	4.486
14	$16639890	9	60.0	4.565
15	$15280780	13	60.0	5.532
16	$14304684	5	60.0	4.378
17	$15808726	23	60.0	6.968
18	$7888245	24	60.0	7.240
19	$18320781	18	60.0	5.899
20	$15672424	6	60.0	4.238
21	$11224136	3	60.0	4.040
22	$5287765	11	60.0	5.125
23	$17704411	12	60.0	5.235
24	$12760095	13	60.0	5.485
25	$8338998	5	60.0	3.886
26	$4386737	21	60.0	6.838
27	$10851054	23	60.0	7.361
28	$15827287	14	60.0	5.569
29	$15347219	25	60.0	7.080
30	$9722697	14	60.0	5.932
31	$8363588	18	60.0	6.042
32	$18980302	4	60.0	3.899
33	$955093	22	60.0	6.643
34	$971052	6	60.0	4.473
35	$15059959	11	60.0	4.993
36	$4475162	16	60.0	6.411
37	$19556124	13	60.0	5.462
38	$9963382	10	60.0	4.534
39	$6507149	22	60.0	6.923
40	$17435712	12	60.0	5.534

```
Company RRR(%) 2.5
Payment Policy (workdays)20
Holdback Amount (%)15.0
Holdback released after completion (days) 45

Average Markup (%) 5.5
Standard Deviation of Markups 1.05
Confidence  (95%) +/- 0.33
```

Appendix G: Sensitivity to the Category Operating Costs

Monte Carlo Study for Sensitivity Analysis of Cash Flow Model to the Category Operating Costs

The operating cost category is varied from 10% to 60% of the total project cost with the recommended markup determined by the cash flow analysis model. The values for other variables which are held constant are shown below. The monte carlo study is simulated for 40 runs randomly generating project duration, total cost and cost distribution of remaining categories for each run. The results for each 40 run simulation are provided in Tables G-3 to G-6 with the average markup, standard deviation and 95% confidence interval calculated for each table. A summary of the Monte Carlo study is shown in Table G-1.

External Variables:

Payment Policy = 20 workdays
RRR = 2.5
Holdback = 15%
Billing Factor = 1.0
Payroll Burden is 24% of labour amount

Table G-1: Summary of Monte Carlo study for operating costs

Operating Costs (%)	Average Markup (%)	Confidence Interval	Upper Limit	Lower Limit
10	6.2	0.37	6.57	5.83
20	6.2	0.38	6.58	5.82
40	6.2	0.37	6.57	5.83
60	6.1	0.38	6.48	5.72

The quantile quantile (q-q) plot is produces for each 40 run simulation to check for normality. If the plot presents a linear pattern then the accuracy of the 95% confidence interval is proved. The data for the q-q plots is contained in Table G-2 with the plots shown in Figures G-1 to G-4.

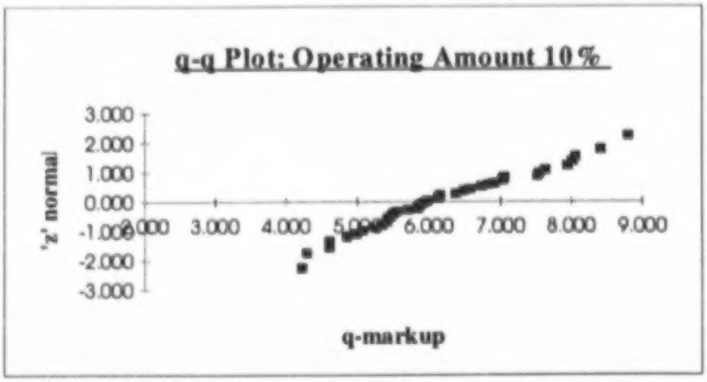

Figure G-1: Q-Q plot for simulation of operating costs = 10 %

Table G-2: Data for quantile-quantile plots for operating cost analysis

	Operating Amount (%), (X)					
#	10	20	40	60	Phi	'z' (Y)
1	4.240	4.367	4.342	4.410	0.013	-2.240
2	4.301	4.502	4.592	4.464	0.038	-1.780
3	4.602	4.554	4.611	4.609	0.063	-1.535
4	4.604	4.588	4.615	4.613	0.088	-1.355
5	4.850	4.606	4.624	4.698	0.113	-1.213
6	4.983	4.684	4.762	4.720	0.138	-1.092
7	5.079	4.865	4.762	4.892	0.163	-0.985
8	5.253	4.866	4.811	4.895	0.188	-0.888
9	5.356	5.021	4.981	4.902	0.213	-0.798
10	5.421	5.101	5.246	4.921	0.238	-0.715
11	5.427	5.231	5.278	5.158	0.263	-0.635
12	5.438	5.273	5.285	5.172	0.288	-0.560
13	5.477	5.495	5.373	5.302	0.313	-0.490
14	5.513	5.498	5.708	5.306	0.338	-0.420
15	5.545	5.610	5.773	5.400	0.363	-0.352
16	5.702	5.661	5.781	5.441	0.388	-0.285
17	5.835	5.744	5.793	5.476	0.413	-0.221
18	5.864	5.932	5.801	5.686	0.438	-0.157
19	5.883	5.946	6.088	5.701	0.463	-0.094
20	5.924	6.053	6.107	5.807	0.488	-0.031
21	5.968	6.245	6.183	5.998	0.513	0.031
22	6.138	6.487	6.275	6.420	0.538	0.095
23	6.144	6.546	6.305	6.448	0.563	0.157
24	6.154	6.556	6.560	6.521	0.588	0.220
25	6.374	6.598	6.597	6.720	0.613	0.285
26	6.500	6.656	6.651	6.725	0.638	0.351
27	6.580	6.742	6.714	6.912	0.663	0.420
28	6.739	6.880	6.902	6.993	0.688	0.490
29	6.826	7.090	6.997	7.155	0.713	0.560
30	6.923	7.259	7.112	7.163	0.738	0.635
31	7.025	7.363	7.128	7.205	0.763	0.715
32	7.050	7.516	7.331	7.283	0.788	0.798
33	7.515	7.577	7.364	7.311	0.813	0.888
34	7.540	7.642	7.449	7.313	0.838	0.985
35	7.644	7.672	7.451	7.462	0.863	1.091
36	7.957	7.883	7.646	7.707	0.888	1.215
37	8.009	7.907	8.010	7.865	0.913	1.355
38	8.074	7.964	8.036	7.936	0.938	1.535
39	8.412	7.979	8.046	8.135	0.963	1.780
40	8.802	7.980	8.199	8.467	0.988	2.241

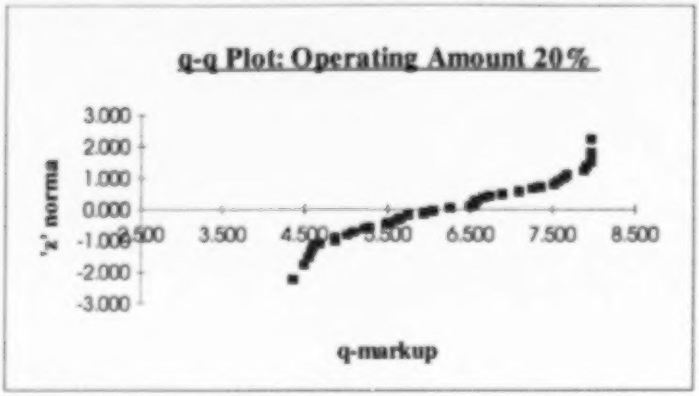

Figure G-2: Q-Q plot for simulation of operating costs = 20 %

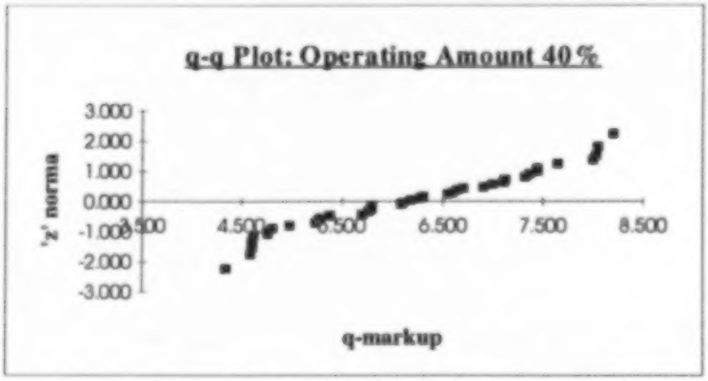

Figure G-3: Q-Q plot for simulation of operating costs = 40 %

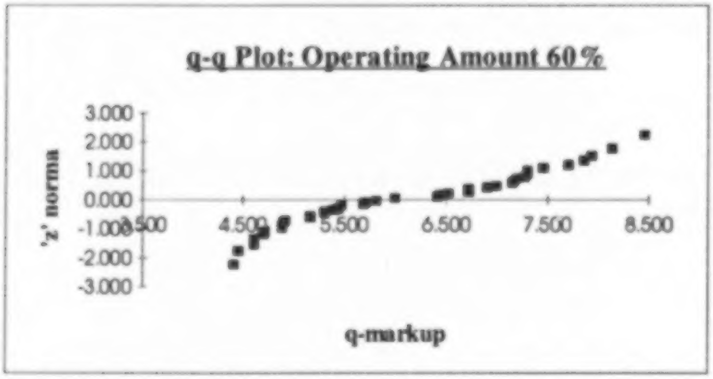

Figure G-4: Q-Q plot for simulation of operating costs = 60 %

Table G-3: Monte Carlo simulation of 40 runs for operating costs = 10 %

```
Run    Project Cost      Duration    Operating(%)    Markup(%)
***    ************      ********    ************    *********
 1       $15677805            6          10.0          4.850
 2       $19774997           12          10.0          5.968
 3       $12350544            9          10.0          4.983
 4       $11374448           24          10.0          8.412
 5       $16534859            7          10.0          4.602
 6       $12894448            4          10.0          4.240
 7        $7454104            8          10.0          5.356
 8         $525679           25          10.0          8.802
 9       $11950270           10          10.0          5.924
10        $6013899           19          10.0          7.644
11       $18430545           20          10.0          7.515
12       $19637394           15          10.0          6.580
13        $9236776           13          10.0          5.702
14        $9564584           24          10.0          7.050
15        $4436090            9          10.0          5.864
16        $1475884           17          10.0          6.739
17        $8932255           11          10.0          5.477
18        $6964104           11          10.0          6.138
19        $5604995           14          10.0          5.545
20        $4628898            6          10.0          5.079
21       $17725750           19          10.0          6.500
22        $1868829           14          10.0          5.883
23       $12301366            7          10.0          4.604
24        $5372940           24          10.0          7.957
25       $16797531            9          10.0          5.438
26       $18797600           24          10.0          8.009
27        $3748556           19          10.0          6.826
28       $12720201           20          10.0          6.923
29       $10256023           24          10.0          8.074
30        $2647391            6          10.0          5.427
31       $17048147           14          10.0          6.154
32        $6151502           16          10.0          5.835
33        $2015062           16          10.0          7.025
34       $11639722           10          10.0          5.421
35        $4215268            7          10.0          5.253
36       $14831982           16          10.0          6.144
37       $14464928           12          10.0          5.513
38       $14480887           19          10.0          7.540
39        $5384173           13          10.0          6.374
40       $17984997            6          10.0          4.301

         Company RRR(%) 2.5
         Payment Policy (workdays)20
         Holdback Amount (%)15.0
         Holdback released after completion (days) 45

         Average Markup (%) 6.2
         Standard Deviation of Markups 1.16
         Confidence  (95%) +/- 0.37
```

Table G-4: Monte Carlo simulation of 40 runs for operating costs = 20 %

```
Run    Project Cost     Duration    Operating(%)    Markup(%)
***    ************     ********    ************    *********
 1        $11865267         5           20.0           5.231
 2         $5928896        14           20.0           5.744
 3        $18345542        15           20.0           6.742
 4        $13401226        15           20.0           6.880
 5         $3000608        13           20.0           6.245
 6        $18577597         5           20.0           5.101
 7         $5512663         7           20.0           4.588
 8         $2552457        15           20.0           7.090
 9        $13665199        20           20.0           7.642
10         $8040677         9           20.0           5.946
11         $6767390        24           20.0           7.907
12         $5791294        17           20.0           7.259
13         $3638964        24           20.0           7.964
14        $11591363        14           20.0           5.610
15         $6151020        19           20.0           7.577
16         $3502663         7           20.0           5.273
17        $18583625         4           20.0           4.502
18        $18712597        19           20.0           7.363
19        $15256364         7           20.0           4.606
20         $2375608        25           20.0           7.883
21         $7847869        12           20.0           5.498
22         $3895608         4           20.0           4.367
23         $2423485        23           20.0           7.516
24        $15336158        20           20.0           7.672
25         $3263279        15           20.0           5.932
26         $1295128        15           20.0           6.598
27        $19379447         7           20.0           5.495
28        $10466911        16           20.0           6.546
29        $16251021         6           20.0           4.554
30         $8330541         7           20.0           4.866
31         $2890197        12           20.0           6.053
32        $11834651        17           20.0           6.656
33         $7386362        14           20.0           6.556
34        $17322871        11           20.0           5.661
35        $13866637        23           20.0           7.976
36        $14987665         7           20.0           5.021
37         $4587047         5           20.0           4.684
38          $634786        20           20.0           6.487
39         $7099102        23           20.0           7.980
40         $4138896         7           20.0           4.865

      Company RRR(%) 2.5
      Payment Policy (workdays)20
      Holdback Amount (%)15.0
      Holdback released after completion (days) 45

      Average Markup (%) 6.2
      Standard Deviation of Markups 1.18
      Confidence  (95%) +/- 0.38
```

Table G-5: Monte Carlo simulation of 40 runs for operating costs= 40 %

```
Run    Project Cost      Duration      Operating(%)       Markup(%)
***    ************      ********     *************       *********
 1      $16296940           19            40.0              6.902
 2      $14016940           15            40.0              6.107
 3      $10560706            4            40.0              4.762
 4       $5616390            4            40.0              4.624
 5      $11712350           22            40.0              7.451
 6       $7760089           14            40.0              6.275
 7       $2007897           15            40.0              6.714
 8      $17329543            7            40.0              4.762
 9      $16849475           19            40.0              6.597
10       $2664815           17            40.0              7.128
11       $3176801           20            40.0              7.646
12       $2824404           20            40.0              7.331
13      $19577626           20            40.0              7.112
14      $19593585            4            40.0              4.615
15      $12991666            5            40.0              4.811
16       $6063240           21            40.0              7.364
17       $9551391           24            40.0              7.449
18       $3615020            9            40.0              5.246
19       $3815157            9            40.0              5.285
20      $18400091            9            40.0              5.278
21      $15935913           13            40.0              5.773
22      $12607351           13            40.0              6.560
23      $11135227            9            40.0              5.793
24       $3894952           22            40.0              8.010
25      $13760296           12            40.0              5.801
26      $11792145           11            40.0              5.305
27       $8024062           19            40.0              6.651
28       $7047966           11            40.0              5.708
29       $9175706           14            40.0              6.183
30       $1255225           15            40.0              6.088
31       $3751322            3            40.0              4.342
32       $4759335           25            40.0              8.046
33       $3967418           10            40.0              5.373
34      $17560297           18            40.0              6.997
35      $12770844            3            40.0              4.592
36       $7826528            4            40.0              4.611
37      $16955160           24            40.0              8.199
38      $16659269            5            40.0              4.981
39      $15187146           24            40.0              8.036
40       $4914199           10            40.0              5.781

          Company RRR(%) 2.5
          Payment Policy (workdays)20
          Holdback Amount (%)15.0
          Holdback released after completion (days) 45

          Average Markup (%) 6.2
          Standard Deviation of Markups 1.15
          Confidence  (95%) +/- 0.37
```

Table G-6: Monte Carlo simulation of 40 runs for operating costs = 60 %

```
Run   Project Cost    Duration    Operating(%)    Markup(%)
***   ************    ********    *************   *********
 1      $7514238         10           60.0          5.701
 2      $1577868         18           60.0          7.155
 3     $13994514         19           60.0          7.163
 4      $9050198         19           60.0          7.462
 5     $18178829         17           60.0          6.521
 6     $10570198         22           60.0          7.865
 7     $17034514         24           60.0          7.311
 8     $14074308          9           60.0          5.807
 9     $11723143         20           60.0          6.912
10     $14035062         16           60.0          6.993
11      $6610608         13           60.0          6.420
12      $1978142         17           60.0          7.205
13     $15074993          6           60.0          4.895
14     $11434582          3           60.0          4.609
15      $5994238          7           60.0          5.172
16     $18595062         23           60.0          8.467
17     $19671261          9           60.0          5.400
18     $13734890         17           60.0          6.725
19     $18215096         12           60.0          5.686
20     $13270780         13           60.0          6.448
21      $6526532         21           60.0          7.283
22     $11134410          4           60.0          4.410
23      $9662286         23           60.0          7.707
24     $10358451         19           60.0          7.313
25      $1941942         24           60.0          7.936
26     $18255644          9           60.0          5.476
27     $10831191          6           60.0          4.921
28      $5575025          3           60.0          4.892
29     $18671877         15           60.0          6.720
30     $19311535          7           60.0          5.158
31     $13871191         11           60.0          5.302
32      $6942765          4           60.0          4.613
33      $6150847         12           60.0          5.998
34      $8150916          3           60.0          4.464
35     $16287493          9           60.0          5.306
36     $10181601          6           60.0          4.902
37      $7717423          9           60.0          5.441
38      $3765162         25           60.0          8.135
39     $10229478          4           60.0          4.698
40     $18862082          6           60.0          4.720

        Company RRR(%) 2.5
        Payment Policy (workdays)20
        Holdback Amount (%)15.0
        Holdback released after completion (days) 45

        Average Markup (%) 6.1
        Standard Deviation of Markups 1.19
        Confidence  (95%) +/- 0.38
```

Single Project Sensitivity Analysis for Operating Costs

The operating cost of a single project is varied from 10% to 60% of the total project cost with the recommended markup determined by the cash flow analysis model. The values for other parameters and cost categories are shown as external and cost variables below. The sensitivity analysis is performed using the project S-curve tabulated in Table G-7 with the results of the analysis shown in Table G-8.

Cost Variables:

Labour = 20%
PRB (24% Lab) = 4.8%
Material = 30%
Equipment = 30%
Operating Costs = variable
Indirect Overhead = 15.2%

External Variables:

Payment Policy = 20 wk dys
RRR = 2.0%
Holdback = 15%
Billing Factor = 1.0
HOOH = $0

The labour cost item is paid out 50% at mid-month and the remaining 50% of period total at the end of the month. The initial cost of the project in period zero is considered an indirect overhead expense. The remaining period cost (after removing operating costs) is distributed according to the allocated percentage of other cost categories.

Table G-7: Project S-curve for single project sensitivity analysis

Date	Period	Cost	Cummulative
Sep-92	0	$12,204.00	$12,204.00
Oct-92	1	$21,276.00	$33,480.00
Nov-92	2	$1,030,000.00	$1,063,480.00
Dec-92	3	$1,190,000.00	$2,253,480.00
Jan-93	4	$1,090,000.00	$3,343,480.00
Feb-93	5	$190,000.00	$3,533,480.00
Mar-93	6	$450,000.00	$3,983,480.00
Apr-93	7	$500,000.00	$4,483,480.00
May-93	8	$210,970.00	$4,694,450.00
Jun-93	9	$34,025.00	$4,728,475.00

Table G-8: Results of single project sensitivity analysis for operating costs

Operating Costs	Markup
10%	3.15%
20%	3.2%
40%	3.3%
60%	3.4%

The calculation of markup for each labour amount is shown in Tables G-9 to G-16.

Table G-9: Cash outflow, single project present value for operating costs = 10%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$1,915	$1,915	0.99	$1,896
1.0	$919	$2,128	$2,911			$1,915	$7,872	0.98	$7,718
1.5				$5,745	$5,745	$92,700	$104,189	0.97	$101,140
2.0	$44,496	$103,000	$140,904			$92,700	$381,100	0.96	$366,301
2.5				$278,100	$278,100	$107,100	$663,300	0.95	$631,262
3.0	$51,408	$119,000	$162,792			$107,100	$440,300	0.94	$414,905
3.5				$321,300	$321,300	$98,100	$740,700	0.93	$691,101
4.0	$47,088	$109,000	$149,112			$98,100	$403,300	0.92	$372,587
4.5				$294,300	$294,300	$17,100	$605,700	0.91	$554,060
5.0	$8,208	$19,000	$25,992			$17,100	$70,300	0.91	$63,673
5.5				$51,300	$51,300	$40,500	$143,100	0.90	$128,333
6.0	$19,440	$45,000	$61,560			$40,500	$166,500	0.89	$147,847
6.5				$121,500	$121,500	$45,000	$288,000	0.88	$253,216
7.0	$21,600	$50,000	$68,400			$45,000	$185,000	0.87	$161,054
7.5				$135,000	$135,000	$18,987	$288,987	0.86	$249,102
8.0	$9,114	$21,097	$28,861			$18,987	$78,059	0.85	$66,623
8.5				$56,962	$56,962	$3,062	$116,986	0.85	$98,863
9.0	$1,470	$3,403	$4,655			$3,062	$12,589	0.84	$10,534
9.5	$0	$0	$0	$9,187	$9,187	$0	$18,374	0.83	$15,223
							PVout =		$4,347,641

Table G-10: Cash inflow, single project present value for operating costs = 10%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117
			Total =	$709,271		PV in =		$4,215,208

Markup for 10% Operate = (4347641 / 4215208) -1 = 3.15%

Table G-11: Cash outflow, single project present value for operating costs = 20%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$1,702	$1,702	0.99	$1,685
1.0	$817	$4,255	$2,587			$1,702	$9,361	0.98	$9,178
1.5				$5,106	$5,106	$82,400	$92,612	0.97	$89,902
2.0	$39,552	$206,000	$125,248			$82,400	$453,200	0.96	$435,602
2.5				$247,200	$247,200	$95,200	$589,600	0.95	$561,122
3.0	$45,696	$238,000	$144,704			$95,200	$523,600	0.94	$493,400
3.5				$285,600	$285,600	$87,200	$658,400	0.93	$614,312
4.0	$41,856	$218,000	$132,544			$87,200	$479,600	0.92	$443,076
4.5				$261,600	$261,600	$15,200	$538,400	0.91	$492,498
5.0	$7,296	$38,000	$23,104			$15,200	$83,600	0.91	$75,719
5.5				$45,600	$45,600	$36,000	$127,200	0.90	$114,074
6.0	$17,280	$90,000	$54,720			$36,000	$198,000	0.89	$175,818
6.5				$108,000	$108,000	$40,000	$256,000	0.88	$225,081
7.0	$19,200	$100,000	$60,800			$40,000	$220,000	0.87	$191,523
7.5				$120,000	$120,000	$16,878	$256,878	0.86	$221,424
8.0	$8,101	$42,194	$25,654			$16,878	$92,827	0.85	$79,227
8.5				$50,633	$50,633	$2,722	$103,988	0.85	$87,878
9.0	$1,307	$6,805	$4,137			$2,722	$14,971	0.84	$12,527
9.5	$0	$0	$0	$8,166	$8,166	$0	$16,332	0.83	$13,531
							PVout =		$4,349,782

Table G-12: Cash inflow, single project present value for operating costs = 20%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117
			Total =	$709,271		PV in =		$4,215,208

Markup for 20% Operate = (4349782 / 4215208) -1 = 3.2%

Table G-13: Cash outflow, single project present value for operating costs = 40%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$1,277	$1,277	0.99	$1,264
1.0	$613	$8,510	$1,940			$1,277	$12,340	0.98	$12,098
1.5				$3,830	$3,830	$61,800	$69,459	0.97	$67,426
2.0	$29,664	$412,000	$93,936			$61,800	$597,400	0.96	$574,202
2.5				$185,400	$185,400	$71,400	$442,200	0.95	$420,841
3.0	$34,272	$476,000	$108,528			$71,400	$690,200	0.94	$650,391
3.5				$214,200	$214,200	$65,400	$493,800	0.93	$460,734
4.0	$31,392	$436,000	$99,408			$65,400	$632,200	0.92	$584,055
4.5				$196,200	$196,200	$11,400	$403,800	0.91	$369,373
5.0	$5,472	$76,000	$17,328			$11,400	$110,200	0.91	$99,812
5.5				$34,200	$34,200	$27,000	$95,400	0.90	$85,555
6.0	$12,960	$180,000	$41,040			$27,000	$261,000	0.89	$231,761
6.5				$81,000	$81,000	$30,000	$192,000	0.88	$168,811
7.0	$14,400	$200,000	$45,600			$30,000	$290,000	0.87	$252,462
7.5				$90,000	$90,000	$12,658	$192,658	0.86	$166,068
8.0	$6,076	$84,388	$19,240			$12,658	$122,363	0.85	$104,435
8.5				$37,975	$37,975	$2,042	$77,991	0.85	$65,908
9.0	$980	$13,610	$3,103			$2,042	$19,735	0.84	$16,513
9.5	$0	$0	$0	$6,125	$6,125	$0	$12,249	0.83	$10,148

PVout = $4,354,064

Table G-14: Cash inflow, single project present value for operating costs = 40%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117

Total = $709,271 PV in = $4,215,208

Markup for 40% Operate = (4354064 / 4215208) -1 = 3.3%

Table G-15: Cash outflow, single project present value for operating costs = 60%

Per	PRB	Operating	IOH	Material	Equip	Labour	Total	PV	PVcost
0.0			$12,204				$12,204	1.00	$12,204
0.5						$851	$851	0.99	$843
1.0	$408	$12,766	$1,294			$851	$15,319	0.98	$15,018
1.5				$2,553	$2,553	$41,200	$46,306	0.97	$44,951
2.0	$19,776	$618,000	$62,624			$41,200	$741,600	0.96	$712,803
2.5				$123,600	$123,600	$47,600	$294,800	0.95	$280,561
3.0	$22,848	$714,000	$72,352			$47,600	$856,800	0.94	$807,382
3.5				$142,800	$142,800	$43,600	$329,200	0.93	$307,156
4.0	$20,928	$654,000	$66,272			$43,600	$784,800	0.92	$725,034
4.5				$130,800	$130,800	$7,600	$269,200	0.91	$246,249
5.0	$3,648	$114,000	$11,552			$7,600	$136,800	0.91	$123,904
5.5				$22,800	$22,800	$18,000	$63,600	0.90	$57,037
6.0	$8,640	$270,000	$27,360			$18,000	$324,000	0.89	$287,703
6.5				$54,000	$54,000	$20,000	$128,000	0.88	$112,541
7.0	$9,600	$300,000	$30,400			$20,000	$360,000	0.87	$313,402
7.5				$60,000	$60,000	$8,439	$128,439	0.86	$110,712
8.0	$4,051	$126,582	$12,827			$8,439	$151,898	0.85	$129,644
8.5				$25,316	$25,316	$1,361	$51,994	0.85	$43,939
9.0	$653	$20,415	$2,069			$1,361	$24,498	0.84	$20,499
9.5	$0	$0	$0	$4,083	$4,083	$0	$8,166	0.83	$6,766
							PVout =		$4,358,345

Table G-16: Cash inflow, single project present value for operating costs = 60%

Per	Cost	BF	Chargeable	Holdback	Billable	Inflow	PV	PVin
0.0	$12,204.00	1.0	$12,204	$1,831	$10,373		1.00	$0
1.0	$21,276.00	1.0	$21,276	$3,191	$18,085	$10,373	0.98	$10,170
2.0	$1,030,000.00	1.0	$1,030,000	$154,500	$875,500	$18,085	0.96	$17,382
3.0	$1,190,000.00	1.0	$1,190,000	$178,500	$1,011,500	$875,500	0.94	$825,003
4.0	$1,090,000.00	1.0	$1,090,000	$163,500	$926,500	$1,011,500	0.92	$934,470
5.0	$190,000.00	1.0	$190,000	$28,500	$161,500	$926,500	0.91	$839,160
6.0	$450,000.00	1.0	$450,000	$67,500	$382,500	$161,500	0.89	$143,407
7.0	$500,000.00	1.0	$500,000	$75,000	$425,000	$382,500	0.87	$332,989
8.0	$210,970.00	1.0	$210,970	$31,646	$179,325	$425,000	0.85	$362,733
9.0	$34,025.00	1.0	$34,025	$5,104	$28,921	$179,325	0.84	$150,051
10						$28,921	0.82	$23,725
10.5						$709,271	0.81	$576,117
			Total =	$709,271		PV in =		$4,215,208

Markup for 60% Operate = (4358345 / 4215208) -1 = 3.4%

Appendix H: Farid and Boyer's FaRM Model Applied to Example Problem of Chapter 4

FaRM Model Applied to Example Problem in Chapter 4

The FaRM model of Farid and Boyer (1985) is used to calculate a project markup for the same problem as the example application in Chapter 4. The model is used for comparison purposes with the Cash Flow Analysis Model discussed in the chapter.

The FaRM model does not use the separate cost categories and therefore only the total period costs are used in the calculation tables. The calculation for present value of cash outflow (period costs) assuming linear uniform cost occurrences is shown in Table H-1.

Table H-1: Present value of cash outflow for example problem

Date	Per. #	Cost (outflow)	PV factor	PVcost
Sep-92	0	$20,000	1.000	$20,000
Oct-92	1	$359,987	0.976	$351,207
Nov-92	2	$123,892	0.952	$117,922
Dec-92	3	$483,443	0.929	$448,925
Jan-93	4	$606,899	0.906	$549,821
Feb-93	5	$1,090,342	0.884	$963,703
Mar-93	6	$1,697,241	0.862	$1,463,526
Apr-93	7	$2,787,583	0.841	$2,345,097
May-93	8	$1,090,387	0.821	$894,931
Jun-93	9	$500,654	0.801	$400,888
Jul-93	10	$140,667	0.781	$109,889
Aug-93	11	$0		$0
Sep-93	12	$0		$0
		PVout=		$7,665,908

The calculation for the cash inflow or the projcet is determined in Table H-2 where the HOOH, holdback and billing factors are applied.

Table H-2: Calculation of cash inflow per period

Per. #	Total Cost	HOOH cost	Charge Cost	Holdback 15%	Bill Amount	Bill Factor	Invoice Amount	Cash Inflow
0	$20,000	$2,879.80	$17,120	$2,568	$14,552	1.04	$15,134	$0.00
1	$359,987	$2,879.80	$357,107	$53,566	$303,541	1.04	$315,682	$15,134.26
2	$123,892	$2,879.80	$121,012	$18,151	$102,860	1.00	$102,860	$315,682.76
3	$483,443	$2,879.80	$480,563	$72,084	$408,479	1.00	$408,478.72	$102,860.37
4	$606,899	$2,879.80	$604,019	$90,602	$513,416	1.00	$513,416	$408,478.72
5	$1,090,342	$2,879.80	$1,087,462	$163,119	$924,343	1.00	$924,342	$513,416.32
6	$1,697,241	$2,879.80	$1,694,361	$254,154	$1,440,207	1.00	$1,440,207	$924,342.87
7	$2,787,583	$2,879.80	$2,784,703	$417,705	$2,366,998	1.00	$2,366,997	$1,440,207.02
8	$1,090,387	$2,879.80	$1,087,507	$163,126	$924,381	1.00	$924,381	$2,366,997.72
9	$500,654	$2,879.80	$497,774	$74,666	$423,108	1.00	$423,108	$924,381.12
10	$140,667	$2,879.80	$137,787	$20,668	$117,119	1.00	$117,119	$423,108.07
11	$0		$0	$0.00	$0.00	1.00	$0.00	$117,119.12
11.5	$0		$0	$0.00	$0.00	1.00	$0.00	$1,330,412.58
	$8,901,095			$1,330,413				$8,882,140.93

The present value of the cash inflow for the project is calculated in Table H-3 by applying the present value factors.

Table H-3: Present value of cash inflow for example project

Date	Per. #	Invoice Amount	PV factor	PVinflow
Sep-92	0	$0.00	1.000	$0.00
Oct-92	1	$15,134.26	0.976	$14,792
Nov-92	2	$315,682.76	0.952	$300,498
Dec-92	3	$102,860.37	0.929	$95,541
Jan-93	4	$408,478.72	0.906	$370,086
Feb-93	5	$513,416.32	0.884	$453,809
Mar-93	6	$924,342.87	0.862	$797,081
Apr-93	7	$1,440,207.02	0.841	$1,211,619
May-93	8	$2,366,997.72	0.821	$1,942,727
Jun-93	9	$924,381.12	0.801	$740,200
Jul-93	10	$423,108.07	0.781	$330,552
Aug-93	11	$117,119.12	0.762	$89,282
Sep-93	11.5	$1,330,412.58	0.744	$1,005,102
			PVin =	$7,351,289

The project markup determined by the FaRM model from the cash output / input ratio and is calculated to be:

Project Markup(FaRM) = outflow / inflow -1 = (7665908 / 7351289) -1 = 4.3 %

Vita

Sheldon Lawrence Schroeder was born August 4, 1967 in Winnipeg, Manitoba, Canada. He received his high school diploma in 1985 from D.P.Todd Secondary School in Prince George, BC. He received a Bachelor of Science in Civil Engineering in 1991 from the University of Alberta in Edmonton, Alberta, Canada. Sheldon entered the M.Sc. program at the University of Alberta in the fall of 1991, specializing in Construction Engineering and Management. During his post graduate education he was involved in numerous research projects in the area of bidding as well as performing teaching assistantship duties for CivE 402 (Construction Methods and Materials), CivE 409 (Project Management), CivE 506 (Construction Estimating and Cost Control). Sheldon worked for an international consulting firm as a junior engineer during the summer, throughout his undergraduate and graduate education.